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AGRICULTURAL MEMORANDUM 913

CLIMATIC ASPECTS OF HORTICULTURE - WITH PARTICULAR REFERENCE TO THE SOUTH OF ENGLAND

by J.R. STARR

Page

I Earliness and the Climate of Southern England

1 Introduction 1

2 Climatic Elements 2

2.1. Radiation and sunshine 3

2.2. Temperature 7

2.2.1. Soil temperature 10

2.2.2. Accumulated temperature 13

2.3. Precipitation 23

2.3.1. Potential evapo-transpiration and irrigation 26

2.4. Humidity 27

3 Damage risk 29

II The Climate of the European Mainland 36

1 Introduction 36

2 Climatic Elements 36

2.1. Radiation and temperature 36

2.1.1. Frost risk 39

2.1.2. Growing season 40

2.2. Precipitation 40

2.2.1. Snow 42

2.2.2 Potential evapo-transpiration and water balance 42

3 Climate of the Netherlands 43

3.1. Transects 43

4 Climate of France 45

4.1. Transects 45

III Climatic Trends: their Implications for Agriculture and Horticulture 48

1 Introduction 48

2 Implications of a change in mean UK air temperature 48

Page

2.1. Growing season 49
2.2. Land capability 49
2.3. Crops 49
2.4. Soil moisture deficits and irrigation need 50
2.5. Temperature 50
2.6. Fuel requirement for glasshouses 51

3. CO_2 Concentration changes 52

References 53 - 54

LEGEND

Fig	
1	Radiation receipts in MJ/m^2 in a. January and b. July. (Cowley 1978)
2 a	Mean daily temperature, $^\circ$C, January to April
b	Mean daily minimum temperature, $^\circ$C, January to April (Climatological Memorandum No. 73)
3	Agroclimatic areas (MAFF Tech Bull No 35)
4	Areas suitable for viticulture (Cochrane 1974)
5	Average Ontario Units (May to October) (Hough 1978)
6	Areas exceeding 2300 and 2500 Ontario Units in 9 years in 10 (Hough 1978)
7	Areas for planting to 50 tonnes/ha in 9 years in 10 (Barrie 1980)
8	Mean number of days with snow lying at 0900 GMT (Climatological Memorandum No 74)
9	'MORECS' map of potential evapo-transpiration for a week in June 1979
10	Hourly mean wind speed (Climatological Memorandum No 79)
11	Once in 50-year gust speed (Climatological Memorandum No 50A)
12	Frequency of wind direction at Edgbaston and Boscombe Down.
13	Probability of occurrence of temperatures below T$^\circ$C during the spring period at Manston.
14	Average daily maximum temperature and average number of dry days and hours of sunshine in Europe. (London Weather Centre Memorandum No 27) for a) July and b) January.
15	May and June accumulated temperature above 6°C (reduced to msl) (Cambridge Agro-met Unit).

TABLES

1. Average of bright sunshine for stations in the South and West (hours per day) (Meteorological Office Publication Met. O. 884)

2. Ratios, with respect to level ground of maximum possible radiation receipts for various slopes and aspects at 51°N (Kaempfert & Morgan, 1952)

3 Decrease in average daily sunshine northwards (hours per day)

4 Effect on sunshine of distance from a coast (MAFF Tech Bull 35)

5 Average daily maximum, minimum and mean temperatures, °C (1941 - 70) in fruit growing areas of England and the near continent (represented by Vlissingen)

6. Average date at which air temperature rises above 6°C in various Agroclimatic areas of southern Britain (MAFF Tech Bull 35)

7 Agroclimatic area averages of 30 cm (1 foot) soil temperature (MAFF Tech Bull 35)

8 Agroclimatic area averages of dates and duration of growing season (MAFF Tech Bull 35)

9 Mean annual values of accumulated day-degrees above 5.6°C (42°F)

10 Ontario Units and Equivalent Mean Season temperature at two target yields for transplanted outdoor bush tomatoes and for the pregerminated seed (National Vegetable Research Station).

11 Altitudes in various Agroclimatic Areas below which a successful bush tomato crop should be obtained for various yields in both 8 and 9 years in 10.

12 Accumulated day-degrees below 16°C at various stations for different crops using typical heating periods - relative to Penzance (after Hogg, 1966) (ie Station accumulated temperatures below 16°C minus Penzance accumulated temperatures below 16°C).

13 Average monthly accumulated heat unit below several base temperatures for areas in southern Britain (MAFF Tech Bulletin 212)

14 Agroclimatic areal average rainfall (MAFF Tech Bull 35)

15 Sample decade of rainfall variations as percentages of average in central and S. England (MAFF Tech Bull 35)

16 Rain-days (rainfall ⩾ 0.2 mm) in the South-west

17 Agroclimatic areal averages of potential evapo-transpiration (pe) showing decrease in pe from south to north and east to west (MAFF Tech Bull 35)

18 Agroclimatic areal averages of medium value of the maximum summer soil moisture deficit (MAFF Tech Bull 35)

19 Irrigation need in early areas based on returning the soil to field capacity at an smd of 25 mm. Column a gives the number of years of need in 20, column b the average requirements (mm) in those years. (Hogg, 1967)

TABLES

20 Agroclimatic areal averages for irrigating (smd returned to 25 mm at 75 mm deficit) over the April to September period - (MAFF Tech Bull 35)

21 Frequency of radiation and wind frost during spring for three stations in Central and Southern England.

22 Mean number of days of air-frost (1946 - 60) (Chandler and Gregory, 1976)

23 The Netherlands: Climatic transect:roughly north to south (Met. O. 856c)

24 France: Climatic transect: roughly north to south (Met O. 856c)

25 Influence of ±25 mm pe change on the estimated return to field capacity date (Wilkinson 1978)

CLIMATIC ASPECTS OF HORTICULTURE - WITH PARTICULAR REFERENCE TO THE SOUTH OF ENGLAND.

I EARLINESS AND THE CLIMATE OF SOUTHERN ENGLAND

II THE CLIMATE OF THE EUROPEAN MAINLAND

III CLIMATIC TRENDS: THEIR IMPLICATIONS FOR AGRICULTURE AND HORTICULTURE

by J R Starr

I EARLINESS AND THE CLIMATE OF SOUTHERN ENGLAND

1. Introduction

The climate of a region is mainly determined by solar radiation and precipitation, factors which in turn decide the natural vegetation and soil classification for certain purposes. Within broad climatic regions are local gradations and anomalies (technically referred to as 'meso-' and 'micro-climate' regions, depending on the scale), attributable to the altitude, relief, distance from the sea etc (Duckham and Masefield, 1970) which, when favourable can be exploited to allow crops to be produced a few days ahead of the main supplies.

In general, then, early areas must have a sufficient supply of radiant energy to ensure adequate soil and air warming and, subsequently, photosynthesis (Hogg, 1967). Early working of the land is also implied and hence a light, freely-draining soil. The major hazards leading to heavy crop losses too (in particular frost and strong winds), must be infrequent over sensitive phases of the cropping cycle or it must be economically advantageous to minimise such effects by shelter, frost protection methods etc.

In England and Wales early areas include S Hampshire, parts of the Isle of Wight, coastal districts of S E Devon, parts of the Tamar Valley, S W Cornwall, the Isles of Scilly, Pembrokeshire coast, the Gower Peninsula, Anglesey and parts of the Lleyn Peninsula. The South-east Region is nearer to the European mainland than any other part of the British Isles. Weather and climate therefore, show some signs of continental influences particularly in extreme years [Conrad's (1946) 'Continentality Index' (a function of average temperature range) achieves a value of 12.5 at Heathrow and only 3.7 at the Isles of Scilly]; in hot summers for example, the Region may be considerably warmer than the West of England and in winter heavy snowfalls with easterly or northerly winds are not uncommon in East Kent. The influence of the Atlantic in winter is felt less in the South-east than in the South-west which is more favoured in terms of early crop production. However the sunny South-coastal areas partly compensate for this especially as this sunniness is apparent in the early months of the year (table 1); irrigation need is generally high in the South-east and desirable for the successful production of shallow-rooted crops. Water-retentive soils such as the Brick Earths are invaluable in this respect.

Table 1

30 year Averages of bright sunshine, hrs/day.

	Jan	Feb	March	April	May
Haverford West	1.72	2.68	4.01	5.86	6.73
Newquay	1.90	2.80	4.18	6.18	7.07
Plymouth	1.81	2.83	4.27	6.10	7.11
Swanage	1.91	2.78	4.36	6.33	7.42
Sandown	2.12	2.92	4.50	6.39	7.62
Eastbourne	2.05	2.86	4.45	6.35	7.57
Dover	1.92	2.61	3.94	5.81	6.99
Margate	1.68	2.54	4.21	6.07	7.20

(Note the high values for Swanage, Sandown and Eastbourne)

2. The Climatic Elements

The climate of various major (particularly early) areas of horticultural production in this country will now be discussed quantitatively in terms of:

2.1. radiation and sunshine

2.2. temperature

2.2.1. soil temperature and growing season

2.2.2. accumulated temperature

2.3.. . precipitation

2.3.1. potential evapo-transpiration and irrigation

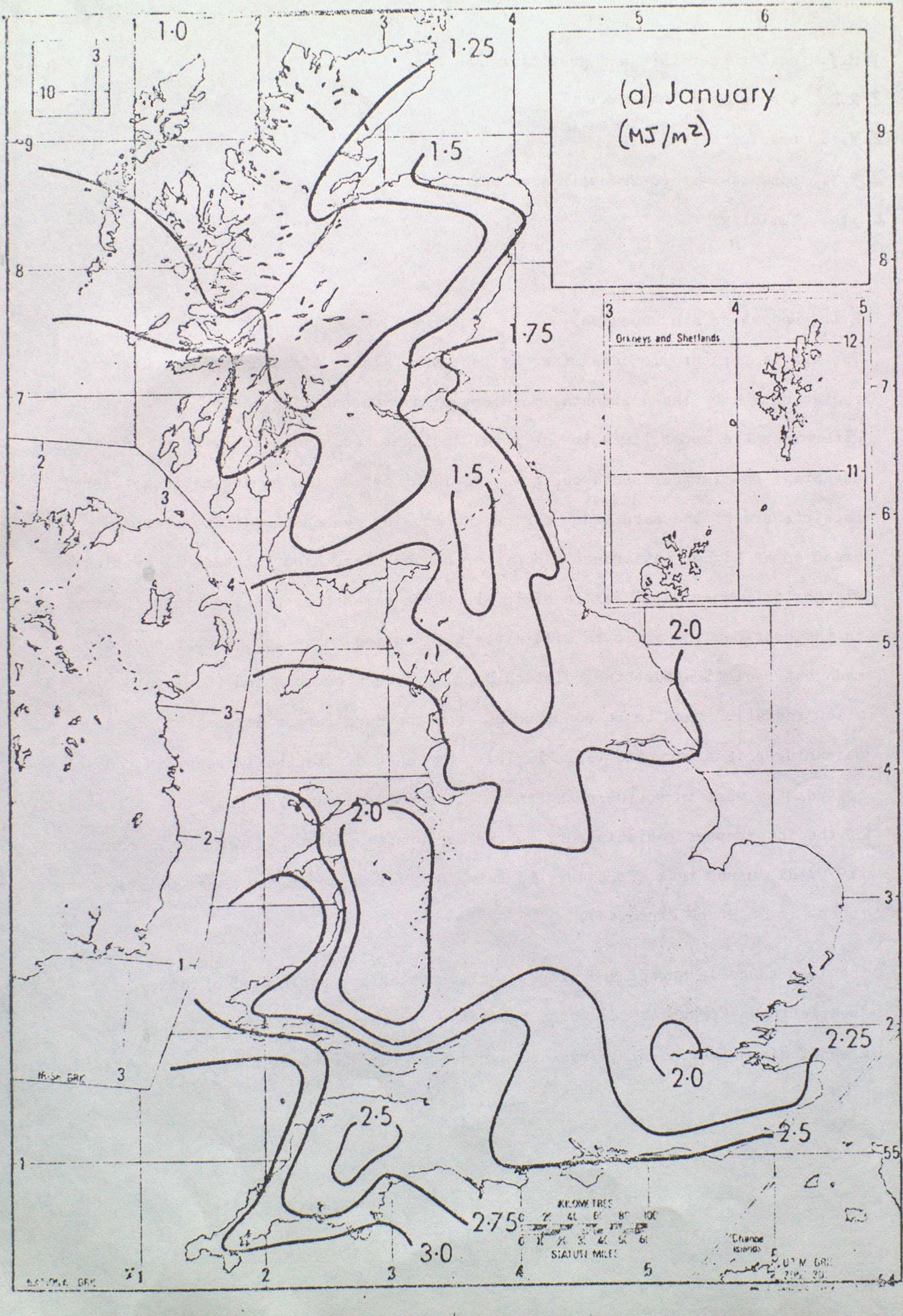
2.4. . humidity

2.1. Radiation and sunshine

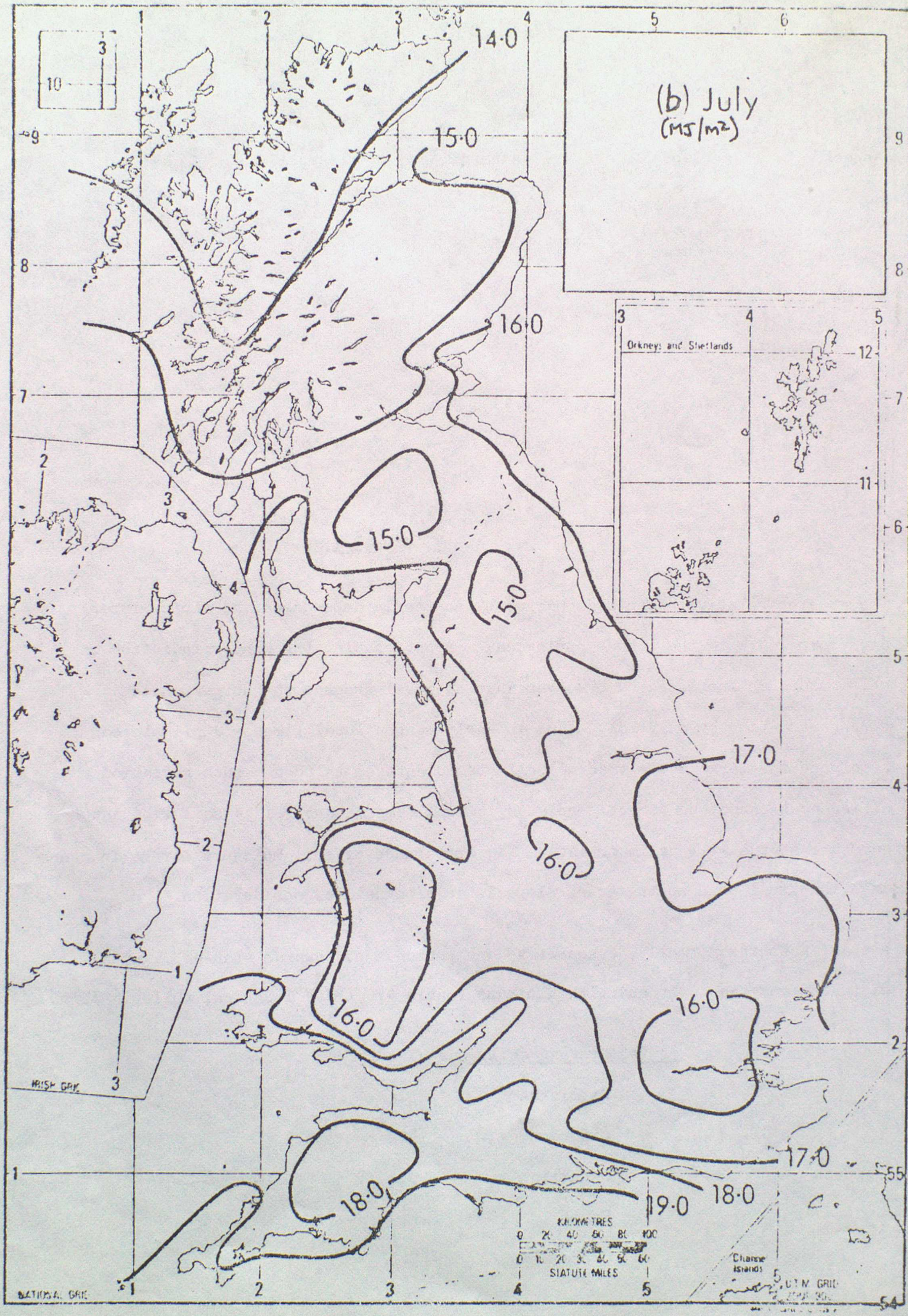
The air temperature is determined by both the balance of incoming and outgoing radiation and by the horizontal movement of air masses ('advection'). Latitude determines the upper limit to the total incident radiation, implying an increasing advantage the further south one goes, at least before the spring equinox; energy receipts are of the same order during the growing season (qv) in the temperat areas as at higher latitudes. In winter on the other hand latitude is critical; Winchester summer half-year receipts are three times those of the winter period; in the Hebrides the ratio is 4:1. Very few routine radiation measurements are made but radiation/sunshine relationships have been established (Cowley 1978) that allow radiation maps to be constructed from the much larger network of stations measuring bright sunshine (Figs 1a, b). One should note the increase in radiation towards the west in southern England. (It should be remarked that the efficiency of the intercepted radiation/dry matter conversion process is very low. Monteith (1977) discusses this efficiency in terms of leaf geometry and gives pointers as to how it might be improved).

The importance of aspect and slope is illustrated in the following table 2 from Kaempfert and Morgan (1952) which tabulates the ratios, with respect to level ground, of maximum possible radiation receipts for various slopes and aspects at 51°N.

Fig 1


(a) January
(MJ/m²)

1·0
1·25
1·5
1·75
1·5
Orkneys and Shetlands
2·0
2·0
2·0
2·25
2·5
2·5
2·75
3·0
KILOMETRES
STATUTE MILES
Channel Islands


(b) July
(MJ/m²)

14·0
15·0
16·0
15·0
15·0
17·0
16·0
16·0
16·0
17·0
18·0
18·0
19·0
Orkneys and Shetlands
KILOMETRES
0 20 40 60 80 100
0 10 20 30 40 50 60
STATUTE MILES
Channel Islands
UTM GRID ZONE 30
NATIONAL GRID
IRISH GRID
55
54

Table 2

Aspect	Slope	1 January	1 April
North	10°	0.43	0.82
	20°	0	0.62
North-east	10	0.57	0.90
	20	0.21	0.74
South-east	10	1.43	1.10
	20	1.83	1.18
South	10	1.57	1.15
	20	2.14	1.26

The greater relative advantage enjoyed by southerly aspects on the short winter days compared with the longer spring days is noticeable; the winter radiation on a 10° slope is increased by 57% over that on level ground, the corresponding spring radiation by only 15%. Thus in early season local ('meso-') climate can reinforce the large scale ('macro-') climate advantages (although such radiation differences cannot be directly related to soil temperatures since soil type and moisture status will be important). The appearance of soil moisture stress in crops in a thin soil on a south-facing slope is an alternative consideration.

Average sunshine normally decreases as one proceeds northwards (table 3), with distance from the coast and with altitude (table 4). (MAFF Technical Bulletin 35)

Table 3 Annual average daily sunshine (hrs)

		Birmingham	3.6		
		Oxford	4.2		
Plymouth	4.6	Shanklin	5.2	Dover	4.6
		Paris	4.9		
		Marseilles	7.2		

Table 4

	Average daily decrease (hrs) for every 10 Km increase in distance from S. Coast	Average daily decrease for every 10 Km increase in distance from nearest coast
Spring	0.025	0.05
Summer	0.04	0.04
Autumn	0.02	0.03
Winter	0.01	0.02

The variation with height is between 0.11 hrs/day/100 m in winter and 0.18 hrs/day/100 m in early summer. (based on averages of 25 representative stations; in the Pennines the corresponding range was 0.09 (December) to 0.23 (June)).

The comparative sunniness of the South coast has already been mentioned in the Introduction (Table 1); in nearly all early areas average January to April sunshine exceeds 3.5 hrs/day, and in much of S. Hants, E. Devon and Cornwall it exceeds 3.75 hrs/day.

2.2. Temperature

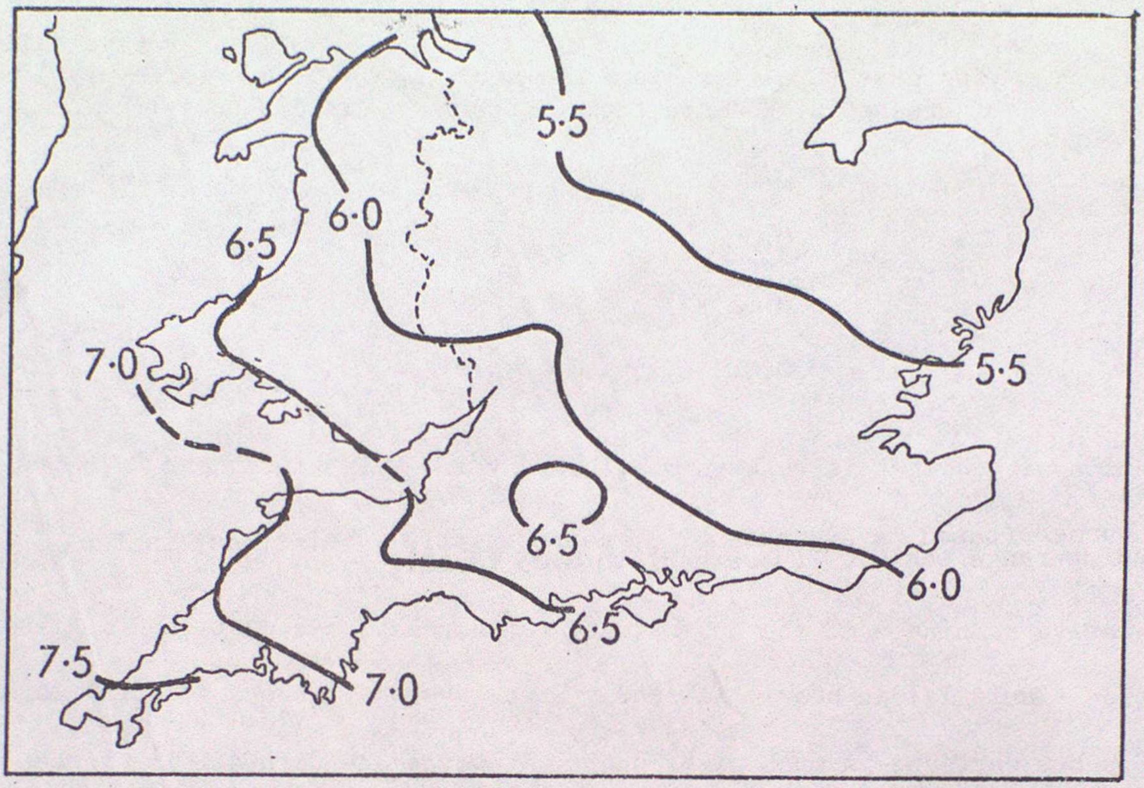
The prevailing south-westerly winds blowing over the relatively warm N Atlantic are responsible for mean temperatures in winter and spring being substantially higher in the west than the east of the country. In general terms the sea surface temperature off South-west England is some 2°C higher than in corresponding latitudes off the East coast in each of the first 4 months of the year.

Fig 2a, b shows the mean and minimum temperatures January to April (reduced to msl). The importance of warm advection is clear from the isotherm pattern. Table 5 shows that the differences between inland and coastal sites are largely due to minimum temperature differences, while the winter advantage of westerly coastal districts is as much due to higher maximum temperature.

Minimum temperatures in winter and spring in Kent are up to 4°C lower than at Penzance and are comparable with those of the W. Midlands and East Anglia. Inland minima are noticeably lower than at the South-east coast; spring and summer maxima are higher.

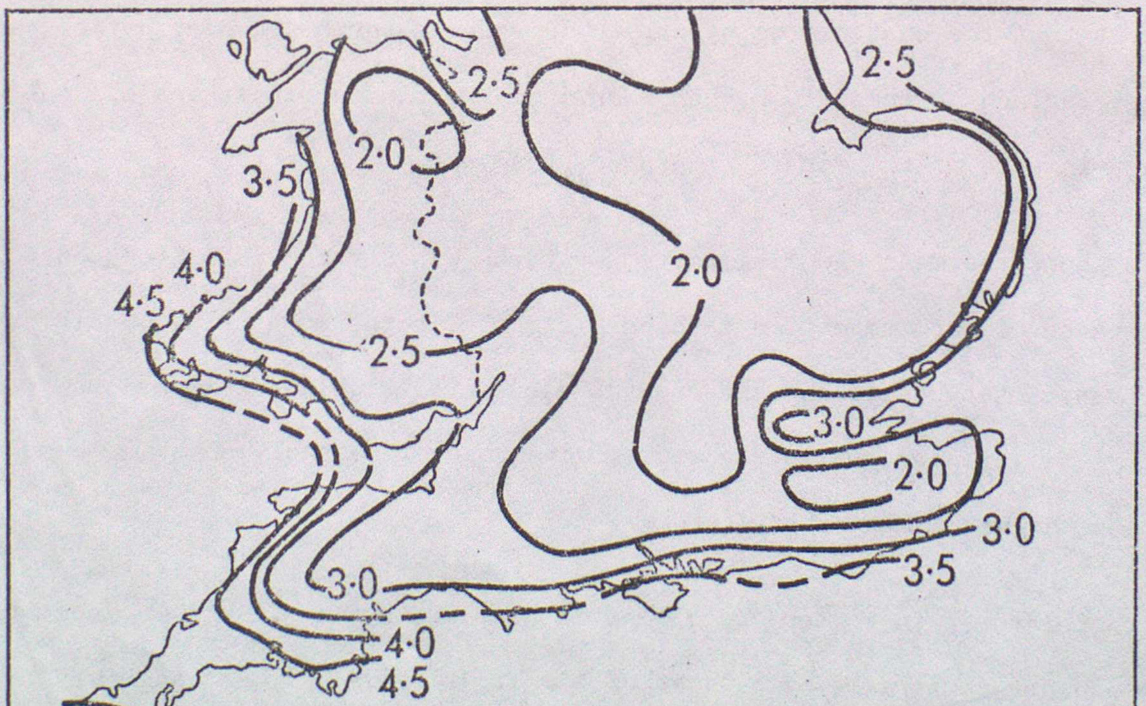
Fig 2

a


5·5
6·0
6·5
7·0
5·5
6·5
6·0
6·5
7·5
7·0

Mean daily temperature(°C): January to April(1941-70)

b


2·5
2·5
2·0
3·5
2·0
4·0
4·5
2·5
3·0
2·0
3·0
3·5
3·0
4·0
4·5
5·0

Mean daily minimum temperature(°C): January to April(1941-70)

Table 5

Average daily maximum, minimum and mean temperatures (°C) 1941 - 70 : for fruit growing areas of England and the near continent.

	Southampton 3m			Stratford-upon-Avon (1) 49m			Terrington St. Clement (2) 3m			Penzance 19m			Vlissingen (3) 1m 51°28'N 3°35'E		
	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean
JAN	7.4	1.6	4.5	6.1	-0.1	3.0	5.4	0.3	2.9	9.4	4.5	6.9	5.0	1.0	3.0
FEB	8.0	1.7	4.9	6.8	0.1	3.5	6.3	0.4	3.3	9.2	3.9	6.5	5.1	0.6	2.9
MAR	10.9	2.9	6.9	10.1	1.1	5.6	9.5	1.7	5.6	10.8	5.3	8.1	8.5	2.5	5.5
APR	14.2	5.2	9.7	13.4	3.4	8.4	13.0	4.0	8.5	13.0	6.6	9.8	11.9	5.4	8.7
MAY	17.4	7.8	12.6	16.7	5.9	11.3	16.1	6.5	11.3	15.3	8.8	12.1	15.9	8.7	12.3
JUN	20.5	10.9	15.7	20.0	9.0	14.5	19.3	9.4	14.3	18.1	11.2	14.7	19.0	12.0	15.5
JUL	21.8	12.7	17.3	21.4	10.9	16.1	20.8	11.4	16.1	19.5	12.8	16.1	20.6	14.1	17.4
AUG	21.5	12.6	17.1	21.0	10.7	15.9	20.6	11.2	15.9	19.5	12.9	16.2	20.9	14.4	17.7
SEP	19.5	10.7	15.1	18.7	9.0	13.7	18.6	9.6	14.1	17.9	11.9	14.9	18.7	12.6	15.7
OCT	15.9	8.0	11.9	14.8	6.0	10.4	14.6	6.8	10.7	15.3	9.9	12.6	14.1	8.9	11.5
NOV	11.1	4.5	7.8	9.7	2.9	6.3	9.3	3.3	6.3	12.1	6.9	9.5	9.4	5.2	7.3
DEC	8.5	2.6	5.5	7.2	0.8	4.0	7.1	1.3	4.2	10.4	5.6	8.0	6.3	2.4	4.4
YEAR	14.7	6.8	10.7	13.8	5.0	9.4	13.4	5.5	9.5	14.2	8.4	11.3	13.0	7.3	10.2

(1) data averaged over 1941-47, 51-70
(2) data averaged over 1941-46, 51-70
(3) data averaged over 1931-60

Many indigenous crops in N W Europe only show substantial growth above about 6°C. Since for early production only the early part of the season is important table 6 shows the average date on which air temperature rises above this value (see Fig 3 for Agroclimatic area key map):

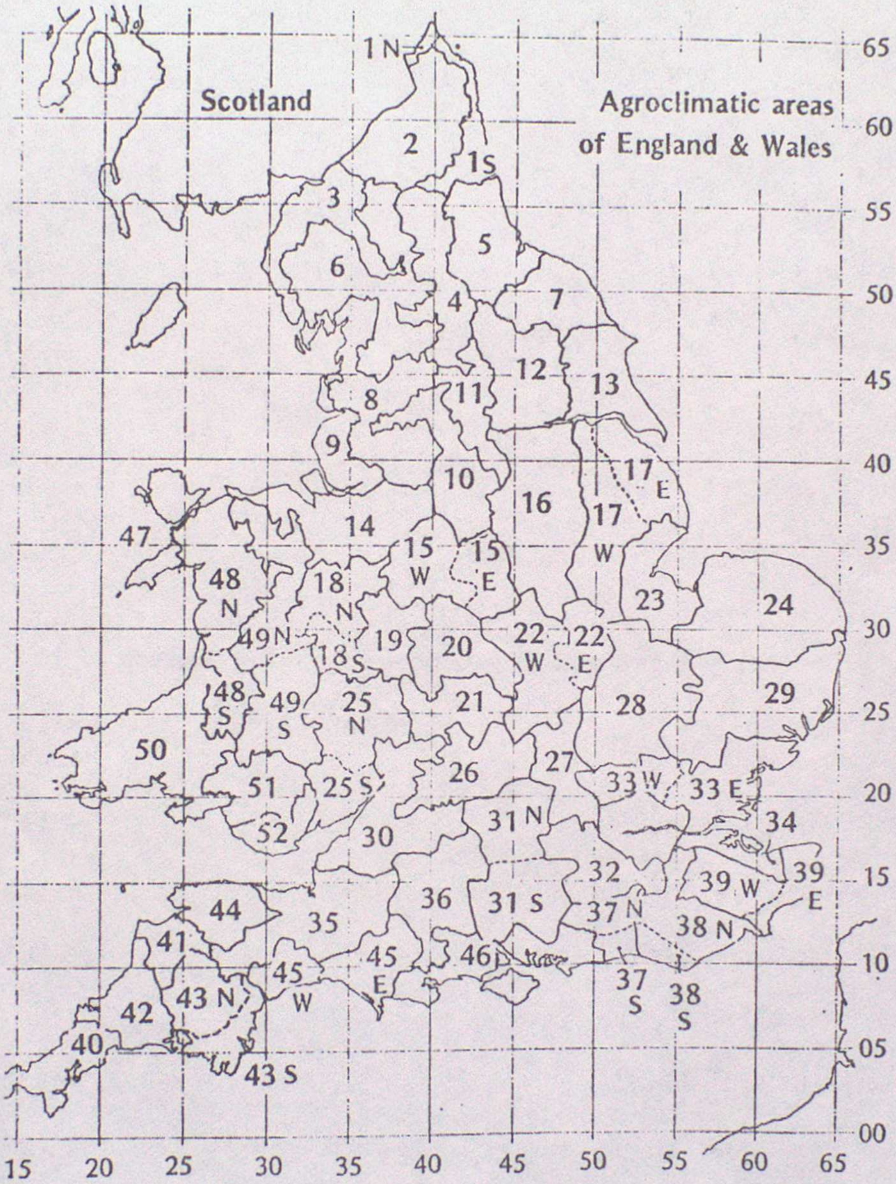
Table 6

Area	Date
40	15 February
31S	17 March
IoW	5 March
39E	15 March
24	22 March
21	19 March
52	15 March

2.2.1 Soil temperature and growing season

Germination will not begin if the soil temperature is low: hence some aspects of the effective growing season are closely connected with soil temperature. The effect of the higher soil temperatures in the South-west (table 7) is made clear in table 8 which shows the mean dates and duration of the growing season. The earliest areas have 40 to 50 more days available for growth than for example East Kent. A district with a long growing season is clearly more versatile and provides greater opportunity for producing more than one crop a year.

Fig 3


Scotland
Agroclimatic areas
of England & Wales
1 N
1 S
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9
10
11
12
13
14
15 W
15 E
16
17 E
17 W
18 N
18 S
19
20
21
22 W
22 E
23
24
25 N
25 S
26
27
28
29
30
31 N
31 S
32
33 W
33 E
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37 N
37 S
38 N
38 S
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60
65

Table 7

30 cm soil temperatures

Agroclimatic Area	Jan	Feb	Mar	Apr	May	Ave. area height (m)
21	3.4	3.4	5.3	8.8	12.4	83
24	3.6	3.7	5.1	8.2	11.3	33
47	4.8	4.7	6.0	8.1	10.6	61
50	4.3	4.2	5.9	8.2	10.8	123
40	5.9	5.8	7.0	9.8	12.5	83
31 S	4.0	4.1	5.3	8.5	11.9	107
I o W	5.3	5.3	7.7	10.5	13.8	56
39 E	4.4	4.4	5.7	8.9	12.7	49

Table 8 Mean dates and duration of growing season

Area	Mean dates	Duration (days)	Change per 100 m height increase
21	Mar 23 - Nov 29	251	- (15 to 20)
24	Mar 26 - Nov 29	248	- (15 to 20)
47	Mar 16 - Dec 18	277	- 20
50	Mar 20 - Dec 16	271	- 20
40	Feb 20 - Jan 8	322	- (30 to 35)
31 S	Mar 22 - Dec 5	258	- (20 to 25)
IoW	Feb 28 - Jan 5	311	- (20 to 25)
39 E	Mar 19 - Dec 13	269	- (20 to 25)

Away from the coast the interquartile range may be expected to be within the range -14 to +21 days .

2.2.2 Accumulated temperatures

In studies which relate plant development and weather air temperature has often been used as a significant variable. A common technique has been to use accumulated temperature above some base temperature with the hope that the accumulated temperature sums might be taken as constant between particular phenological events. This technique assumes that plant development rate varies linearly with temperature (which is only true for relatively small temperature ranges) but still provides a useful developmental index since it pays due regard to both temperature level and duration of exposure to that level.

The relative earliness of different areas may be compared (as one option) by accumulating temperatures above 5.6°C (table 9).

Table 9

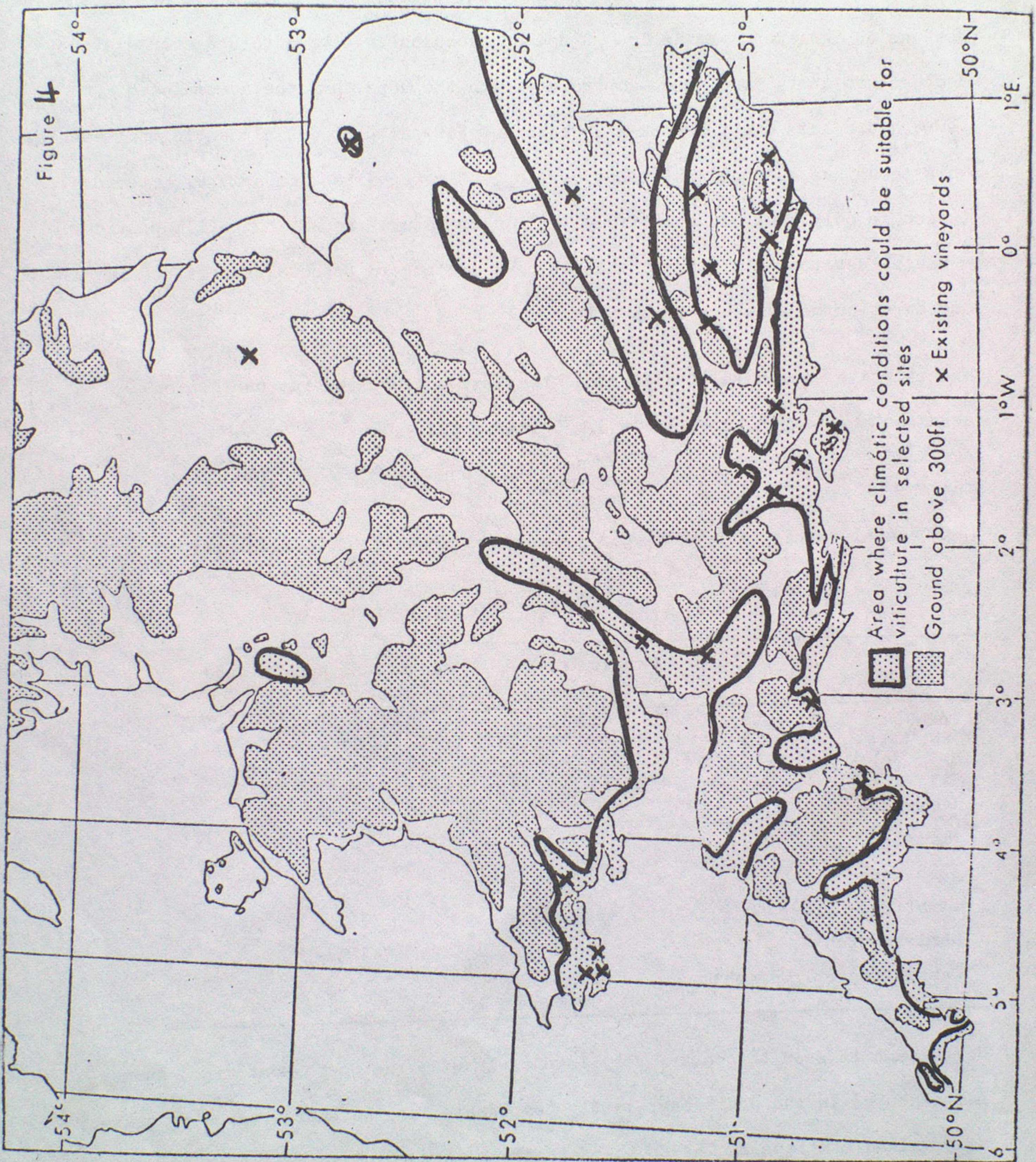
Mean annual values of accumulated day-degrees above 5.6°C for the period 1959-78

	Height (m)	Mean annual accumulated day-degrees
Goudhurst	85	1775
East Malling	39	1888
Dungeness	6	1907
Margate	16	2034
Penzance	19	2131
Stratford-upon-Avon	49	1785
Christchurch	4	1951
Terrington St. Clement	3	1748

North Kent is seen to compare very favourably with the South-west since summer temperatures in the South-east partly compensate for the shorter growing season; some inland stations in the South-east appear no more advantageous than parts of the Midlands and East Anglia. (The effect of 'continentality' shows clearly in Fig 15.)

Fig 4

Figure 4


Area where climatic conditions could be suitable for viticulture in selected sites
Ground above 300ft
× Existing vineyards
54°
53°
52°
51°
50°N
1°E
0°
1°W
2°
3°
4°
5°
6°

Accumulated day-degrees above 10°C, between May and October have been used to define areas where certain marginal 'exotic' crops such as the vine or sweetcorn are unlikely to be climatically limited in their development. Continental viticulture records indicate 1000 degree-days above 10°C to be a pre-requisite for high yields of high quality wine; British experience points to satisfactory yields and quality with 750 units providing soil temperature, aspect and frost incidence are favourable. Fig 4 sketches suitable areas (Cochrane 1974).

(Note: the success of viticulture in, say, the Rheinhesse area of Germany is a result of high growing season temperatures rather than the high solar radiation, Thompson and Barrie, 1978).

A refinement to the simple linear response is to assume that plant development rate varies parabolically with air temperature above some base at which development is zero. The so-called "Ontario Unit" is an example of the latter system. It was originally developed for soya beans and has since been applied to sweetcorn and to other tropical crops being grown in a temperate environment such as sunflowers and outdoor tomatoes.

The Ontario Unit consists of a day and a night term;

Day term $Y = 3.33\ (TMAX-10) - 0.084\ (TMAX-10)^2$

Night term $X = 1.8\ (TMIN-4.4)$

TMAX is the day maximum air temperature °C

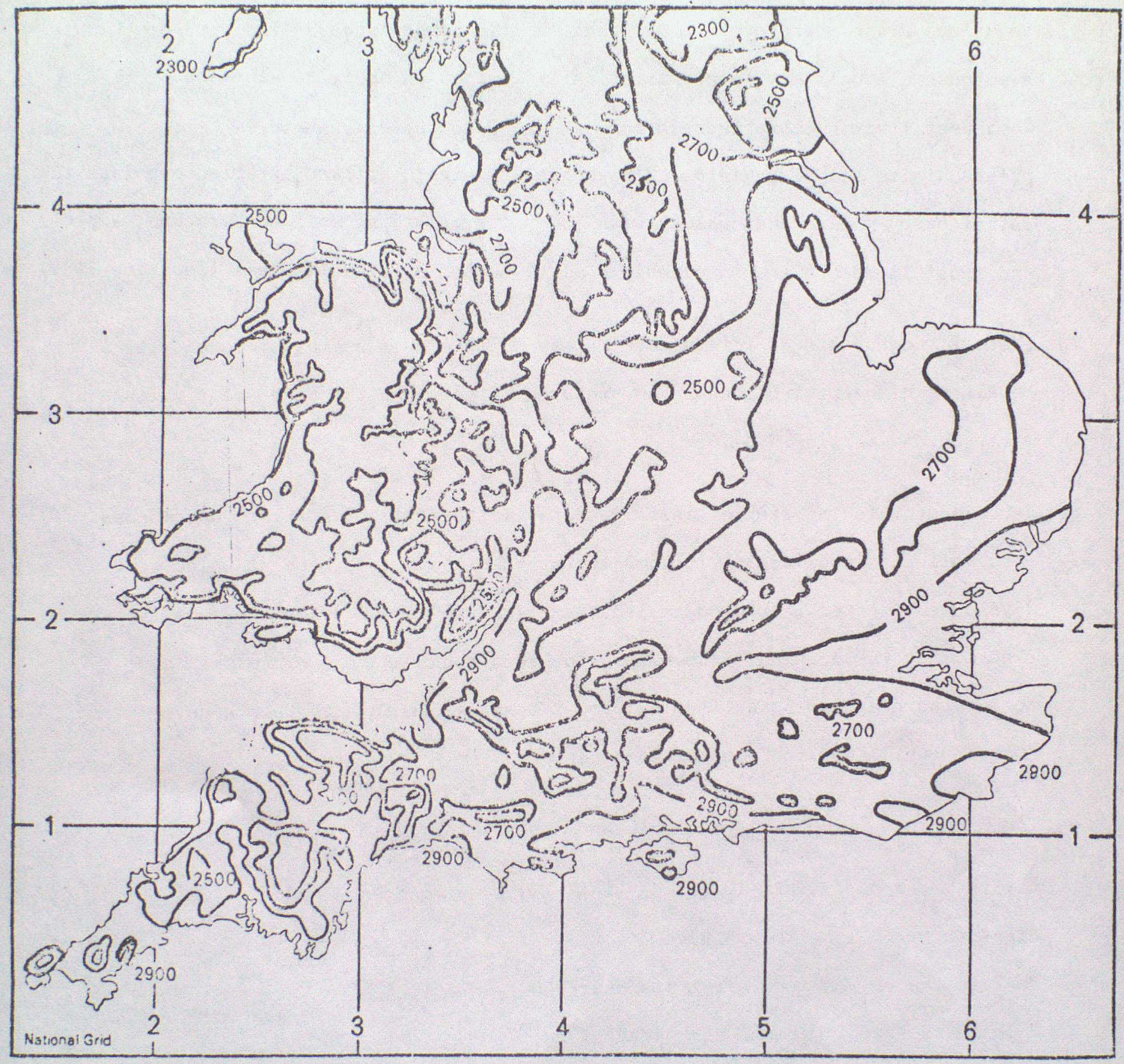
TMIN is the night minimum air temperature °C

The day term has a base of 10°C and represents a near linear variation between 10 and 20°C, but with a steady decrease above 20°C with Y reaching a maximum value at 32°C.

The night term is linear above a base of 4.4°C.

The Ontario Unit, $OU = (Y + X)/2$.

Fig 5.


2
3
6
4
3
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1
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3
4
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6
2300
2300
2500
2700
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2500
2700
2500
2500
2700
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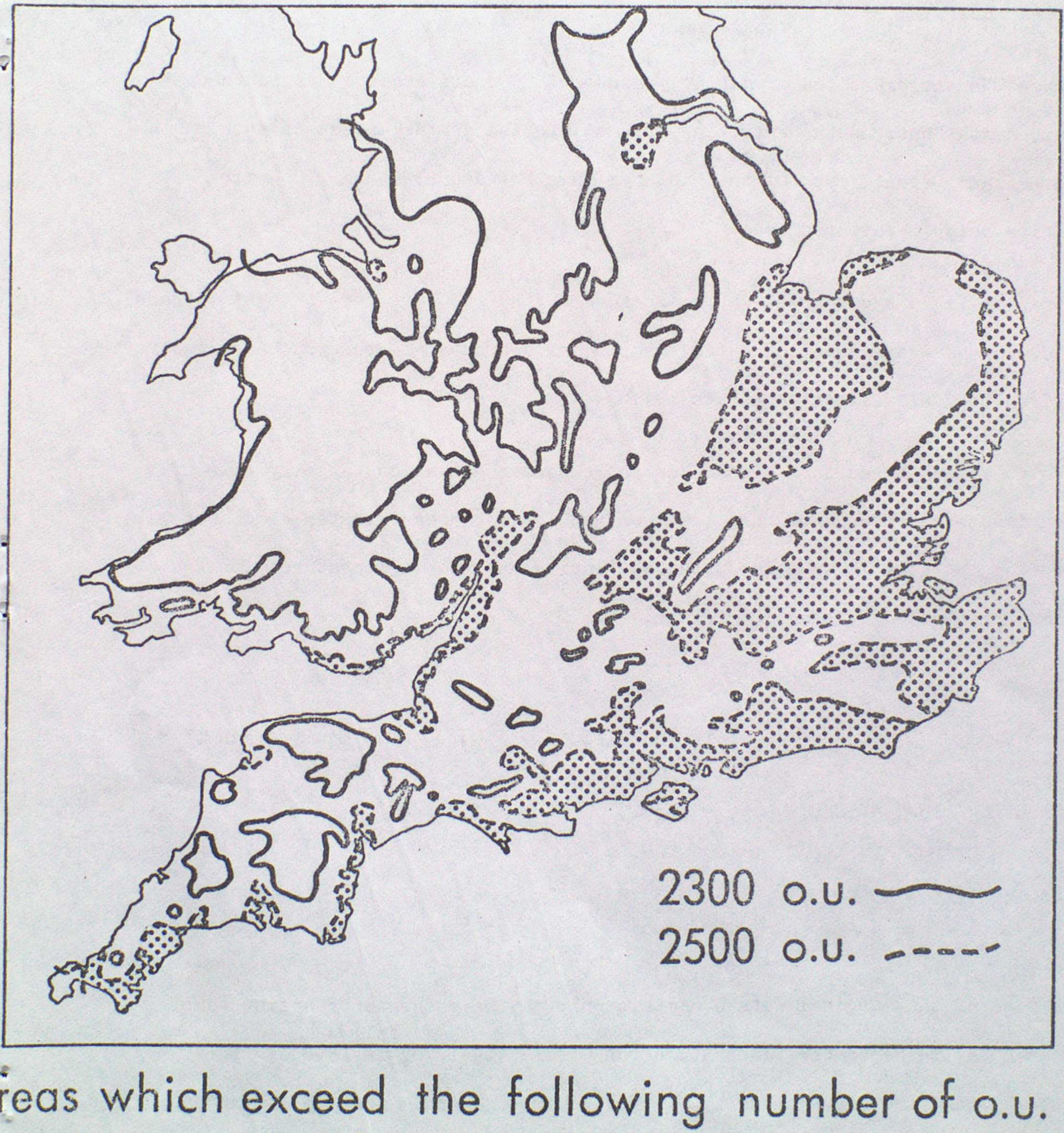
2500
2500
2900
2900
2700
2900
2700
2900
2700
2900
2900
2900
2900
2500
2900
National Grid

Great Britain Average Ontario Units (May-Oct)

Isopleths at:- 2300 2500 2700 2900

Fig 6


2300 o.u.
2500 o.u.

Areas which exceed the following number of o.u. for
9 years in 10

The justification for these formulae is not easy to find in the literature, but the day term would appear to represent the effects of temperature on photosynthesis and the night term could be a crude representation of how temperature affects respiration.

Average OUs are presented in fig 5: values of 2900 are exceeded in south-east Essex, north Kent, south Hants, the Isle of Wight and small areas of Avon, Somerset and Devon; much of the Midlands have between 2500 and 2700 with Cheshire being a favoured area.

The map in fig 6 shows areas which exceed 2300 and 2500 OUs for at least 9 years in 10, areas where sweetcorn, for example, should have greatest success if care is given to field selection (Hough 1978).

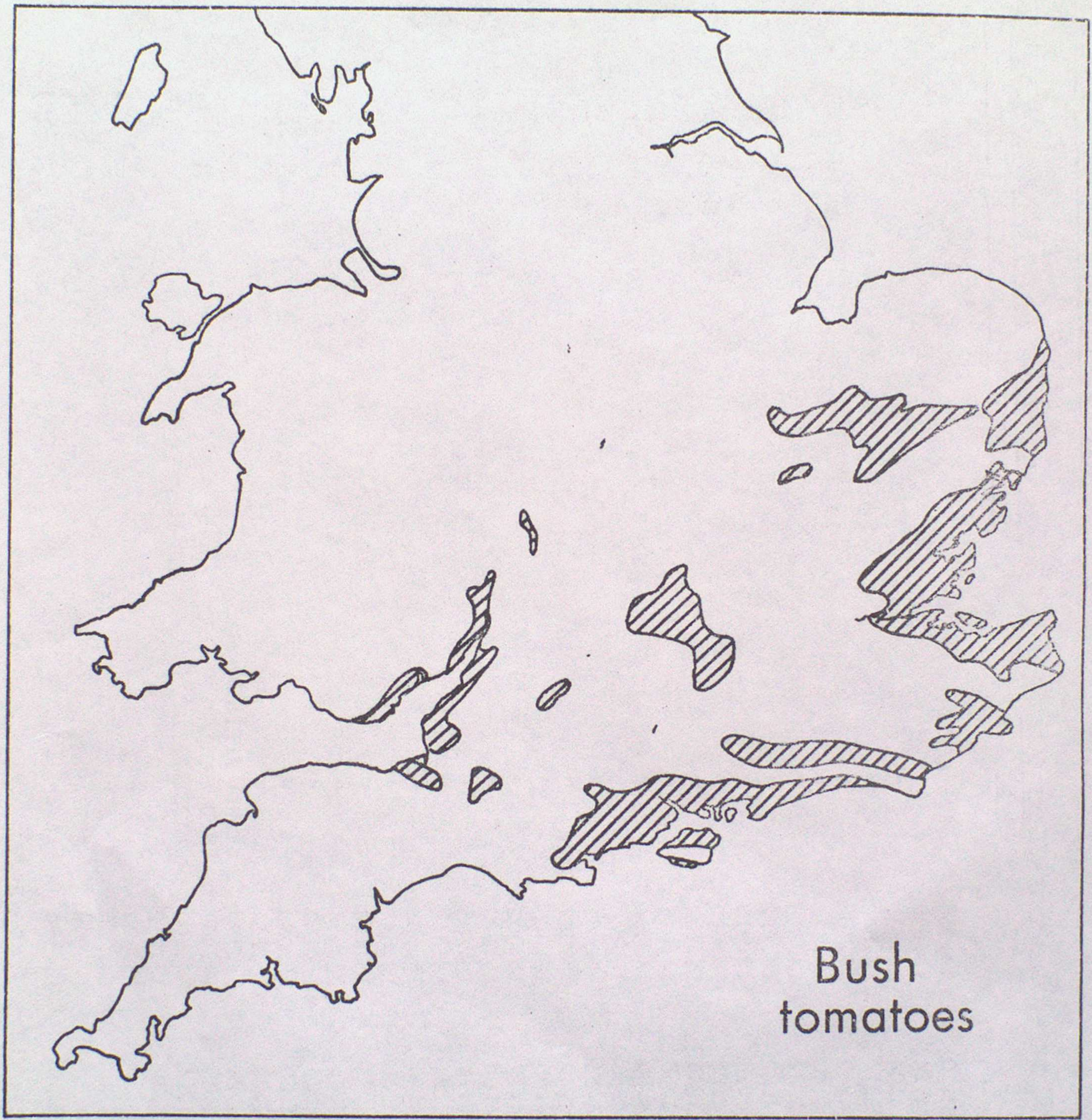
OU calculations based on National Vegetable Research Station target yields of young transplanted outdoor bush tomatoes and for the pregerminated seed are presented in table 10 together with the 'equivalent mean temperature' for the season represented by these OU totals.

Table 10

	Target yield t/ha	OU	Equiv. mean temp.
1 Planting (15/5 - 30/9)	37.5	2152	14.12
	50	2345	15.01
2 Sowing (1/5 - 30/9)	37.5	2650	15.22
	50	2844	15.98

Some idea of the marginal nature of this crop may be gathered by noting that the mean May to September temperature for Oxford (1941-70) is 15.0°C; for Northern Italy the figure is 21.5°C. Fig 7 maps the areas where, planting to 50 tonnes/ha, satisfactory yields 9 years in 10 may be expected. Table 11

Fig. 7


Bush
tomatoes

Planting to 50 tonnes/hectare, 9 yrs in 10

Table 11

AGRO-CLIMATIC AREA	MEAN AREA HEIGHT (M)	MEAN TEMP* °C	MEAN TEMP+ °C	MEAN LAST FROST	MAX. HEIGHTS (M) FOR TARGET YIELD: SOWING To 37.5 t/ha 9 yrs in 10	MAX. HEIGHTS (M) FOR TARGET YIELD: SOWING To 37.5 t/ha 8 yrs in 10	MAX. HEIGHTS (M) FOR TARGET YIELD: PLANTING To 37.5 t/ha 9 yrs in 10	MAX. HEIGHTS (M) FOR TARGET YIELD: PLANTING To 50 t/ha 9 yrs in 10
9	28	14.10	14.268	LATE APRIL				
14	65	14.24	14.630	"			71	
21	83	14.34	14.838	"			132	
22W	117	14.14	14.842	"			166	
22E	81	14.30	14.786	"			167	
23	5	14.40	14.430	"			158	
24	33	14.42	14.618	"			98	
25N	117	14.22	14.922	"			130	
25S	105	14.28	14.910	"			180	39
26	137	14.22	15.042	"		3	178	37
27	107	14.46	15.102	"			200	59
28	56	14.58	14.916	"			210	69
29	49	14.66	14.954	"			179	38
30	91	14.60	15.146	"		10	186	45
31N	107	14.54	15.182	"		42	218	77
31S	107	14.40	15.042	"		48	224	83
32	81	14.60	15.086	"			200	59
33W	97	14.72	15.302	"		32	203	67
33E	40	14.98	15.220	"		68	244	103
34	58	15.14	15.488	"		54	230	89
35	103	14.24	14.858	"	44	99	275	134
36	124	14.26	15.004	"			170	29
37N	64	14.46	14.844	"			194	53
37S	64	14.74	15.124	"			167	26
38N	79	14.46	14.934	"		38	214	73
38S	70	14.74	15.160	"		7	182	41
39W	80	14.60	15.080	"		44	220	79
39E	49	14.94	15.234	"			207	66
40	83	14.24	14.738	EARLY APRIL	2	57	232	91
43S	81	14.38	14.866	MID APRIL			150	9
45W	110	14.14	14.800	LATE APRIL			171	30
45E	102	14.32	14.932	"			160	19
46	45	14.84	15.110	"		6	182	41
50	123	13.48	14.218	"		36	212	71
52	103	14.38	14.998	MID APRIL			63	
ISLE OF WIGHT	56	15.06	15.396	LATE APRIL		16	191	52
					29	84	259	118

+ CALCULATED VALUE AT MEAN SEA LEVEL. (1/5 - 30/9)

* AT MEAN AREA HEIGHT (1/5 - 30/9)

summarises the altitudes below which a successful bush tomato crop should be obtained for various yields in both 8 and 9 years in 10.

Accumulated temperatures below a working base have been taken by Hogg (1968) as having a direct economic application in relation to potential horticultural sites since it is an index of glasshouse heating requirements. Although solar heating and windspeed will be important accumulated temperature comparisons of various areas using typical heating periods can be useful.

Table 12 presents accumulated degree-days below about 16°C in excess of corresponding values at Penzance.

Table 12

Crop	Weymouth	Cheltenham	Littlehampton
Tomatoes	220	450	400
Cucumber	220	511	408
Lettuce	219	436	386
Carnations	225	456	389
Chrysanthemums	169	342	297

Taking 10 degree-days as equivalent to the heating provided by about 720 gals of oil/ha of glass some 3000 gals more oil are needed for 1 ha of tomatoes at Cheltenham, for example, than at Penzance. Table 13 summarises average monthly degree-days below various bases for various areas.

Table 13

DAY DEGREES BELOW SEVERAL BASE TEMPERATURES

Estimated average monthly degree-days

	South West Coast						South Coast except Devon and Cornwall						South Wales						South East Midlands					
	Base temperature						Base temperature						Base temperature						Base temperature					
Month	°C 7·2 °F 45	10·0 50	12·8 55	15·6 60	18·3 65	21·1 70	7·2 45	10·0 50	12·8 55	15·6 60	18·3 65	21·1 70	7·2 45	10·0 50	12·8 55	15·6 60	18·3 65	21·1 70	7·2 45	10·0 50	12·8 55	15·6 60	18·3 65	21·1 70
January	85	220	375	525	680	855	115	265	415	570	725	885	125	280	435	585	745	900	185	340	495	650	805	960
February	80	195	335	480	630	790	115	250	390	530	670	810	115	250	390	530	670	810	165	305	450	585	725	865
March	55	165	320	475	610	755	70	185	340	495	650	805	70	185	340	495	650	805	120	245	400	555	710	865
April	20	80	200	345	495	645	30	100	210	355	505	655	30	100	210	365	505	655	55	140	260	405	555	705
May	—	20	80	200	340	495	—	20	80	190	340	495	—	30	90	205	355	510	5	45	110	220	355	510
June	—	—	20	75	185	325	—	—	20	75	185	330	—	—	30	80	190	325	—	5	45	110	220	360
July	—	—	—	40	120	245	—	—	—	40	110	230	—	—	—	40	125	250	—	—	20	65	150	270
August	—	—	—	40	130	265	—	—	—	40	125	250	—	—	5	50	150	280	—	—	20	65	165	280
September	—	—	15	70	175	325	—	—	15	60	170	315	—	—	30	95	210	355	—	15	55	135	250	390
October	—	15	85	210	370	525	—	15	90	210	370	525	—	40	130	260	410	570	25	65	170	310	460	620
November	20	100	235	385	535	685	30	125	270	415	570	720	40	150	300	445	600	750	95	210	360	510	660	810
December	50	170	325	480	635	790	95	230	385	545	700	855	90	230	385	540	700	850	155	310	465	620	775	930
YEAR	310	965	1,990	3,325	4,905	6,700	455	1,210	2,215	3,525	5,120	6,875	470	1,265	2,345	3,690	5,310	7,060	805	1,680	2,850	4,230	5,830	7,565

2.3. Precipitation

Period averages of rainfall (table 14) necessarily obscure the important year-to-year and month-to-month variability.

Table 14 Areal average rainfall (mm)

Area	J	F	M	A	M	J	J	A	S	O	N	D	Year
21	58	43	44	44	59	48	54	70	57	55	67	61	660
24	55	45	40	40	46	49	55	66	52	54	66	55	623
47	101	73	66	63	72	62	71	88	93	96	110	109	1004
50	131	89	82	78	84	76	85	110	119	125	139	140	1258
40	113	79	78	60	72	57	73	87	88	100	118	122	1047
31 S	79	59	49	50	55	50	59	72	69	78	94	84	798
I o W	77	53	52	49	62	49	54	73	73	80	89	83	794
39 E	62	48	44	43	50	46	56	64	60	65	78	67	683

A sample decade of such variations for southern England is tabulated as percentages of average for various periods in table 15.

Table 15

	1	2	3	4	5	6	7	8	9	10
1 month	25	47	62	75	87	99	113	132	155	205
2 months	44	61	73	82	92	101	112	123	140	172
3 months	53	67	77	86	94	102	110	119	133	159
4 months	58	71	79	87	95	102	108	117	130	153
5 months	61	73	81	89	96	103	108	116	127	146
6 months	63	74	83	91	97	102	107	115	124	144
12 months	73	81	88	92	95	99	104	112	121	135

Hogg noted that rainfall tends to be least variable in spring, most variable in autumn and that almost all land for horticulture has less than 750 mm of precipitation. The relatively dry February to June period (see table 14) is advantageous to many horticultural enterprises by allowing early working of the land although in the South-east many shallow-rooted crops may require irrigation in this period; see section 2.3.1.

Distribution of rainfall within a month can be quantified by the number of 'rain-days' (table 16), a useful data format when studying opportunities for 'work-day' planning.

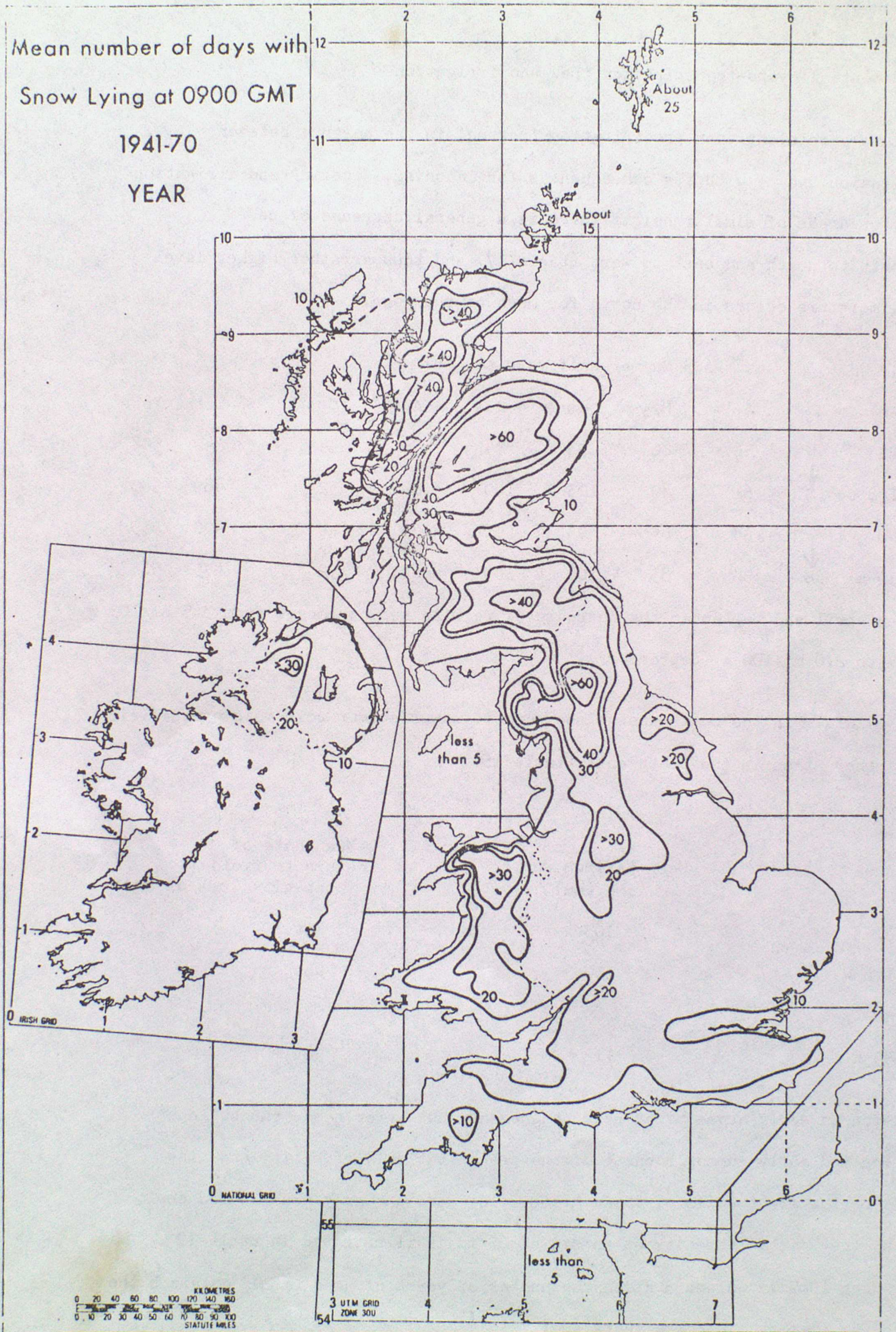
Table 16 Rain-days (rainfall $\geqslant$ 0.2 mm)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
East Malling	17	14	12	13	13	11	12	14	13	13	16	17	165
Penzance	22	18	16	14	14	13	14	16	17	17	21	22	204

(The probability of the occurrence of certain daily, monthly, yearly etc rainfall totals can be presented in terms of a 'return period' - the average interval between events in which rainfall totals reach (or exceed) a specified amount in a given time span. The 'return periods' of given amounts of precipitation occurring over various periods from 1 minute to 1 month duration have likewise been quantified by the Meteorological Office; these expressions of rainfall variability and probability are invaluable aids for estimating, for example, drainage specifications required to deal with 'run-off' from glasshouses).

Snow cover will impede some horticultural activities and may in particular cause damage to nursery stock and glasshouses as well as presenting an increased potential flood risk on melting. On the positive side, snow cover can act to 'blanket' crops and land against unduly severe cold spells. The mean number of days with snow lying at 0900 GMT is mapped in Fig 8. Southern coastal areas and the South-west are seen to average less than 10 days a year of cover.

Fig 8



Mean number of days with Snow Lying at 0900 GMT 1941-70

YEAR

About 25
About 15
>40
>40
>40
>60
>40
>60
>30
>30
>30
>20
>20
>20
>10
10
20
30
40
less than 5
less than 5
IRISH GRID
NATIONAL GRID
UTM GRID ZONE 30U
KILOMETRES
0 20 40 60 80 100 120 140 160
0 10 20 30 40 50 60 70 80 90 100
STATUTE MILES

2.3.1 Potential evapo-transpiration (pe) and irrigation

Perhaps more relevant than precipitation 'per se' is the balance between precipitation and pe with its consequences for leaching, flooding and irrigation need. For areas of similar height there is a general decrease of pe from south to north and east to west (table 17) and thus a rather higher level of soil moisture occurs in the north for much of the year.

Table 17 Mean Summer half year pe (mm)

Area		Apr	May	June	Jly	Aug	Sept	Total	Year
21	N	56	80	93	94	75	44	442	508
I o W	↓ S	61	89	103	100	84	52	489	580
40	W	68	84	93	91	76	48	470	535
39 E	↓ E	58	85	102	100	84	52	475	563

(between April and September the decrease of pe with height ranges from 3.5 mm/100 m (April) to 2.0 mm/100 m (September))

Higher rainfall in the South-west also leads to lower summer soil moisture deficits (smd's) there than in the South-east (table 18).

Table 18

Area	Mean Maximum summer smd (mm)	Mean date of return to field capacity (loss of smd)
21	103	Nov 19
I o W	107	Nov 6
40	89	Oct 5
39 E	112	Nov 20

Irrigation in early areas might seem unnecessary but water needs can build up in spring and early summer because of the precipitation variability and also because of the light soils of these areas. The need in early areas based on returing the soil to capacity at an smd of 25 mm is illustrated in table 19 (after Hogg 1967). Column a gives the number of years of need in 20, column b the average requirements in those years (mm).

Table 19

	April - May a	April - May b	April - June a	April - June b
Southampton	15	56	18	104
Penzance	15	43	18	76
Scilly	16	56	18	99
Tenby	13	42	16	74
St Ann's Head	14	43	17	76
Holyhead	14	51	17	91

Over the April to June period 150-220mm may be needed in the driest seasons to meet the full demands of pe. Areal average figures for an irrigation scheme (smd returned to 25 mm at 75 mm deficit) over the April to September period are given in Table 20.

Table 20

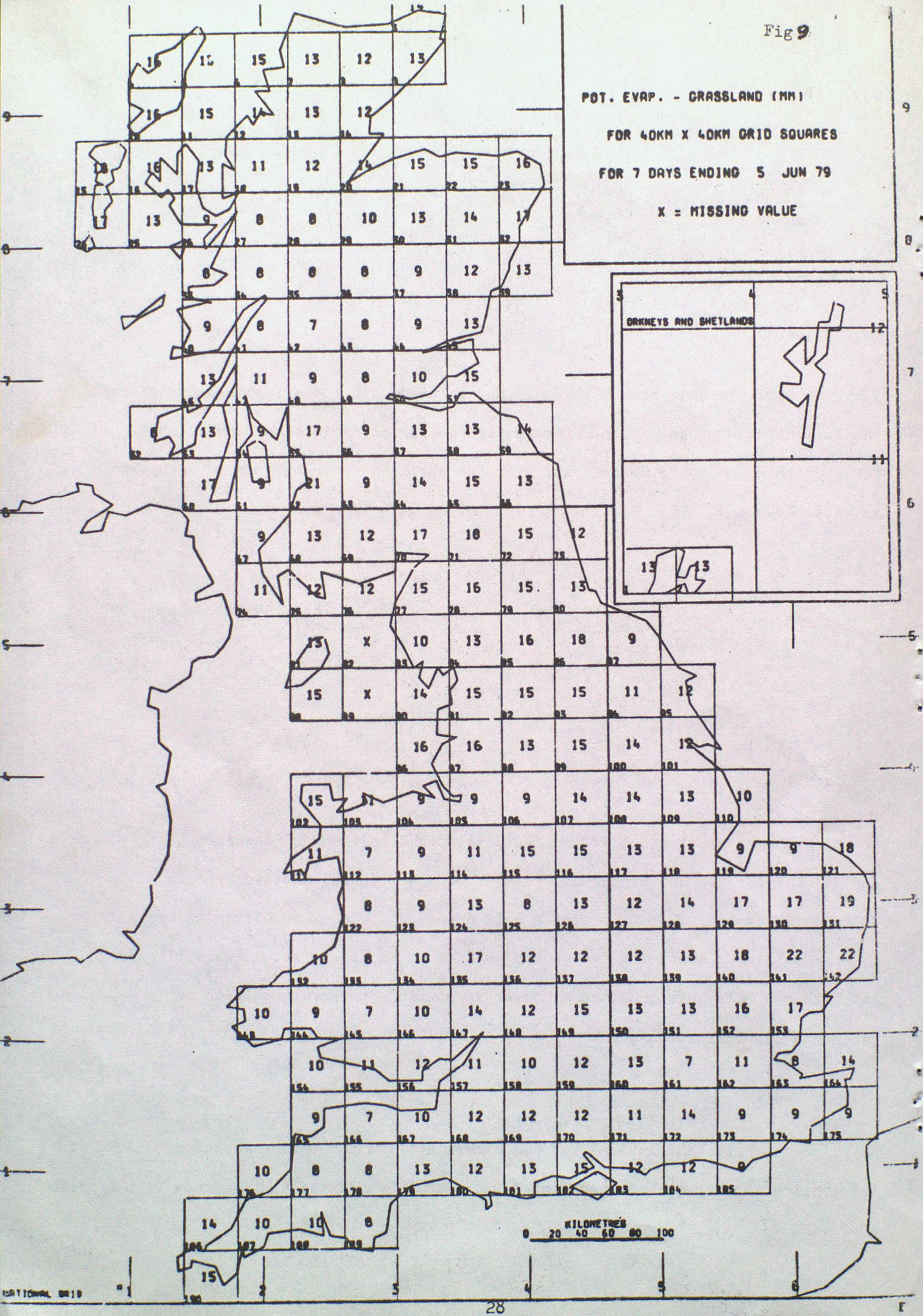
Area	Frequency of need (years in 20)	Need in 5th driest year (mm)	Mean (mm)
21	19	185	120
I o W	19	210	140
40	15	115	75
39 E	19	250	160

Recently the Meteorological Office has developed a soil moisture information service for farmers and growers. The Met. Office Rainfall and Evaporation Calculating System (MORECS) presents data on pe, smd etc averaged over squares of sides 40 km. By combining the weekly pe data in an appropriate square (fig 9) with his own raingauge readings a grower is now in a powerful position to calculate his irrigation need.

2.4. Humidity

Relative humidity (RH) information has direct application to horticulture because of the implication for the incidence of certain pests and diseases (see maps : L P Smith 1962).

Fig 9



POT. EVAP. - GRASSLAND (MM)

FOR 40KM X 40KM GRID SQUARES

FOR 7 DAYS ENDING 5 JUN 79

X = MISSING VALUE

ORKNEYS AND SHETLANDS
KILOMETRES
0 20 40 60 80 100
NATIONAL GRID

In general terms relative humidity variations are the inverse of temperature variations: thus seasonally, highest values occur in winter and the lowest in summer although the range is small. Diurnal variations are large, the mean at Kew being a 20% change in RH with a July maximum (88% at 0300 hrs to 58% at 1500 hrs), and a January minimum (87% at 0300 and 82% at 1500 hrs).

Over the year and particularly in July the increasing diurnal range of temperature with distance from the sea exerts a dominating influence on mid-afternoon RH values (Chandler and Gregory 1976) resulting in a decrease from high values at the coast to substantially lower values inland (eg 80% in the South-west, 75% along the South-east coast and below 60% in the Oxfordshire, Bucks area in July at 1500 hrs).

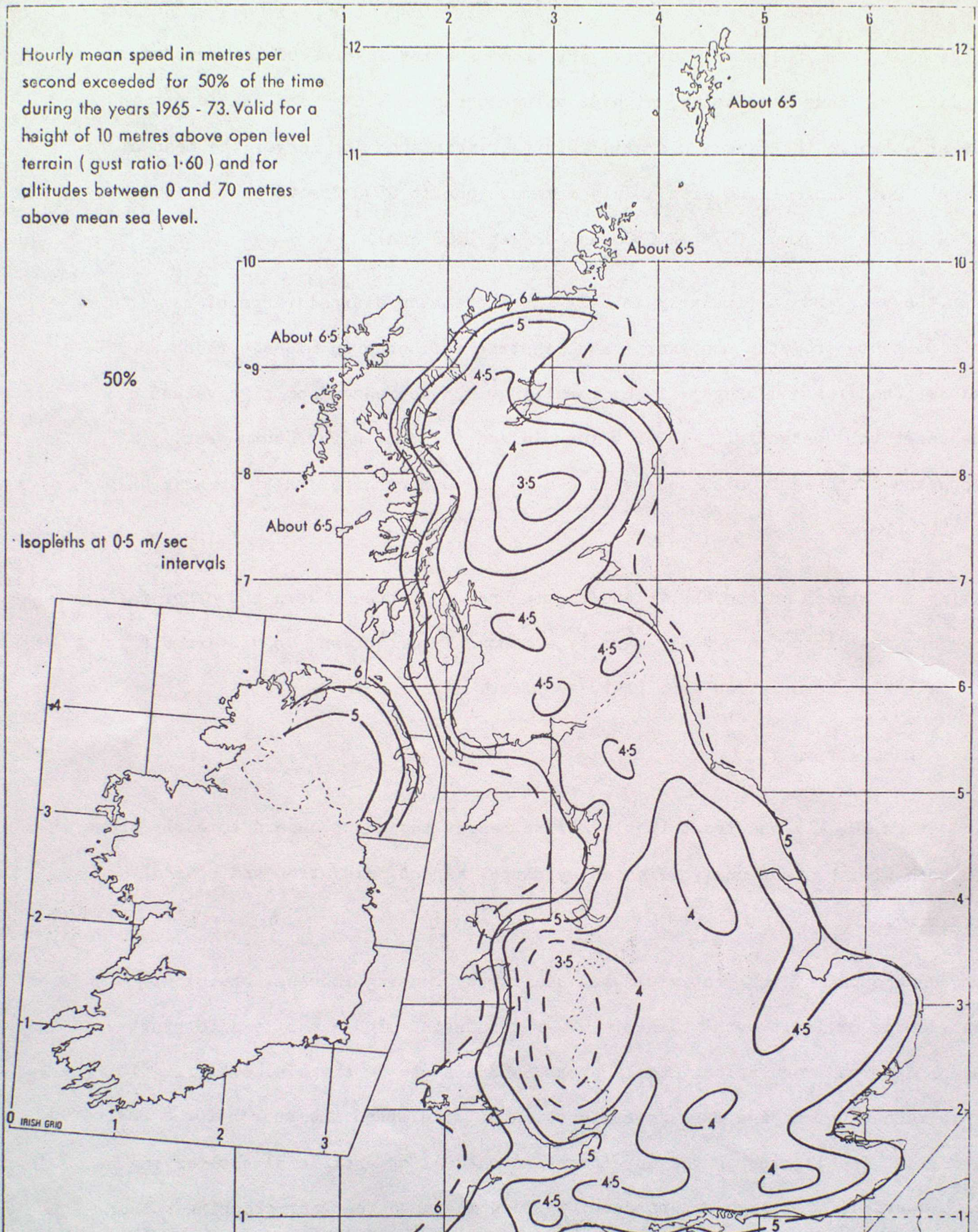
During the winter months the inland/coastal contrast breaks down and other factors such as wind direction and air-mass type become important and usually result in only a small RH variation from place to place.

3. Damage risk

Wind (figs 10, 11) and frost (table 21) represent the major hazard to early crops and both will be profoundly affected by slope, aspect, elevation and coastal proximity.

Wind damage can affect crop yield and quality by causing lodging, bruising, leaf damage or 'salt burn' (Grace, 1977); persistent high winds lead to stunted and/or deformed vegetation. Early areas tend also to be the windiest (figs 10, 11) and since mechanical damage is a power function of wind speed the search for a sheltered (and frost free!) site or the investment in natural or artificial shelter may be well rewarded for a high return crop; in some instances earlier cropping rather than increased cropping has been reported (van Rhee, 1959).

Over the year as a whole over open, level country south-west to west winds prevail but the occurrence of cool winds from a northerly quadrant is a comparatively frequent event (Fig 12).



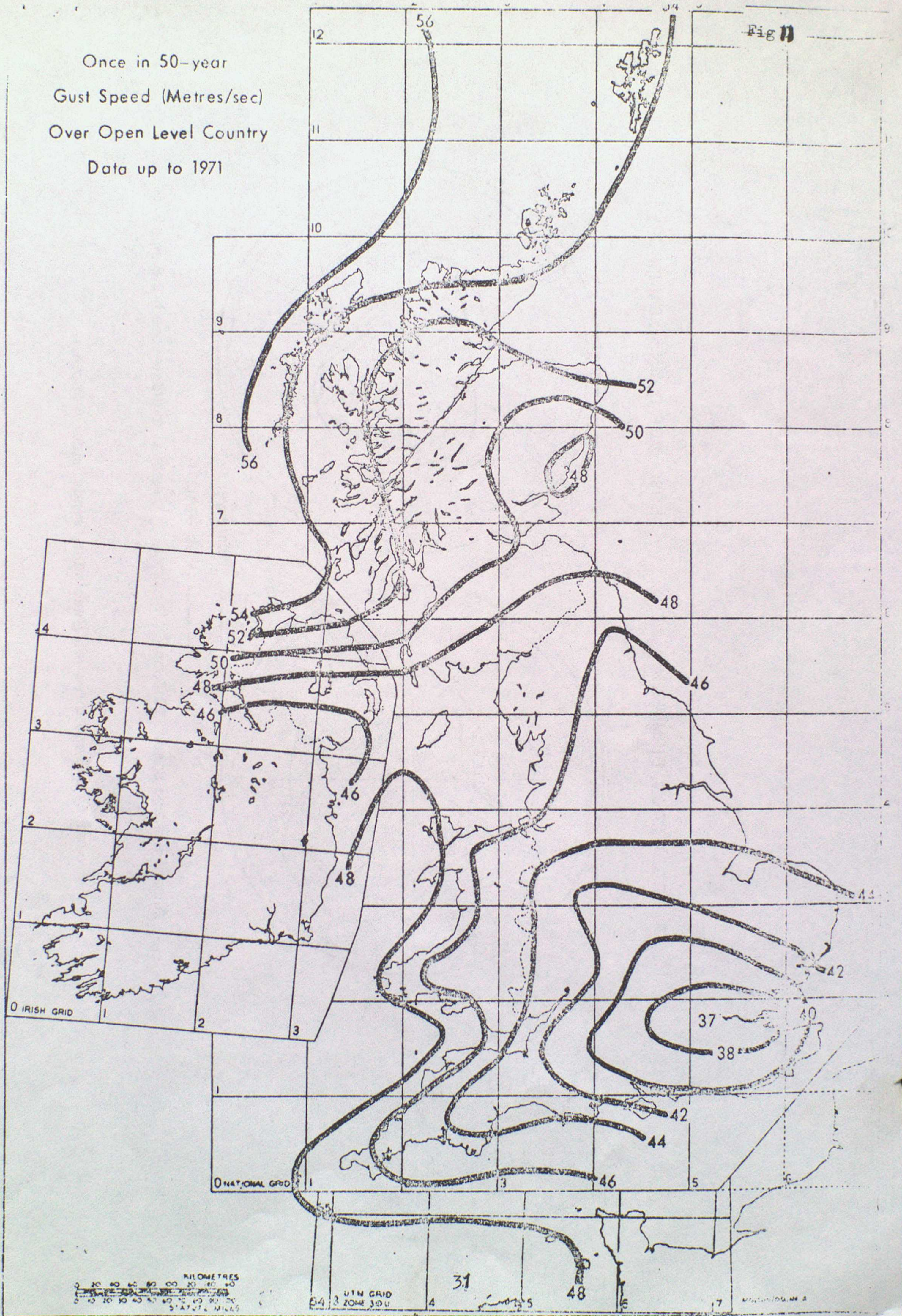
Hourly mean speed in metres per second exceeded for 50% of the time during the years 1965 - 73. Valid for a height of 10 metres above open level terrain (gust ratio 1·60) and for altitudes between 0 and 70 metres above mean sea level.

50%

Isopleths at 0·5 m/sec intervals

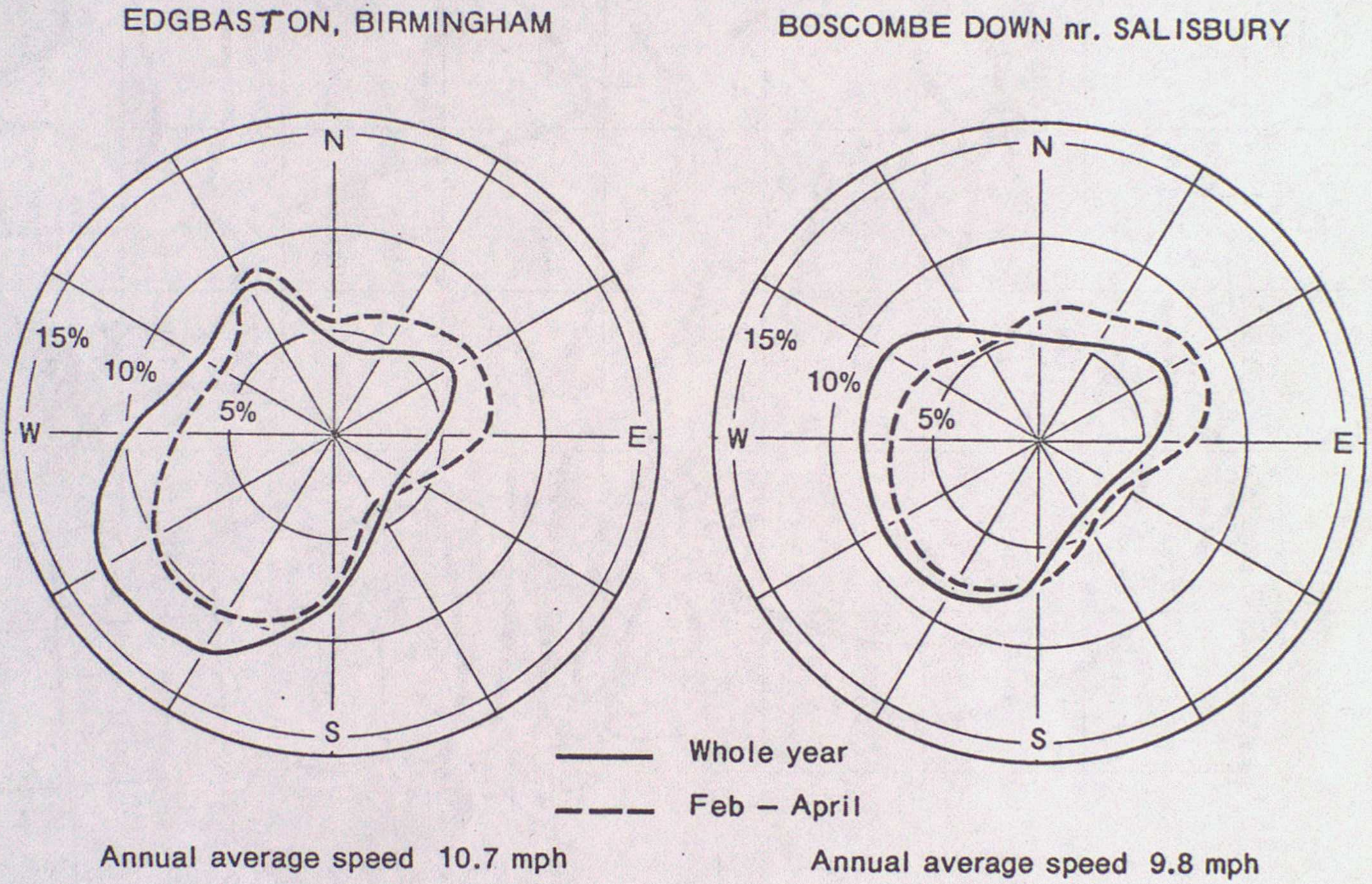
About 6·5
About 6·5
About 6·5
About 6·5
About 5
6
5
4·5
4
3·5
5·5
IRISH GRID
NATIONAL GRID
U.T.M. GRID ZONE 30U
KILOMETRES
0 20 40 60 80 100 120 140 160
0 10 20 30 40 50 60 70 80 90 100
STATUTE MILES

Fig 11



Once in 50-year
Gust Speed (Metres/sec)
Over Open Level Country
Data up to 1971

56
56
54
52
50
48
48
46
54
52
50
48
46
46
48
44
42
40
37
38
42
44
46
48
0 IRISH GRID
0 NATIONAL GRID
UTM GRID ZONE 30U
KILOMETRES
STATUTE MILES



Frequency of wind direction (excluding winds under 4 m.p.h.)

Fig 12

Table 21

Frequency of Radiation and Wind Frosts
during 1 April - 2 June (Roe 1980)

Station	Type of Frost	Number of occasions	% Total
Gatwick (1959-78)	Radiation	121	96
	Wind	5	4
	Total	126	100
Manston (1961-78)	Radiation	23	74
	Wind	8	26
	Total	31	100
Abingdon (1959-78)	Radiation	76	84
	Wind	14	16
	Total	90	100

(wind-frost defined: 10m wind $\geq$ 7 kts, 0900Z screen min temp $\leq 0^{\circ}C$, cloud cover $\geq$ 5 oktas with generally wind NW through N to E and small differences between screen and grass min temperatures.)

Table 22 again confirms the ameliorating effect of coastal proximity on minimum temperatures particularly for West coast stations (Falmouth, Valley).

Table 22

Mean number of days of air frost

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Gorleston	7.8	9.3	5.0	0.7	0.1	-	-	-	-	0.3	1.7	5.0	29.9
Cambridge	13.7	14.0	10.2	4.5	0.7	-	-	-	0.1	2.5	6.1	10.5	62.3
Birmingham	11.1	12.5	8.3	0.9	-	-	-	-	-	0.6	2.5	6.2	42.1
Valley	6.3	7.7	4.7	1.0	-	-	-	-	-	-	0.8	2.4	22.9
Manston	11.2	8.5	6.3	1.9	0.1	-	-	-	-	-	3.0	10.6	41.6
Abingdon	12.5	12.0	9.3	4.0	0.2	-	-	-	0.1	1.1	6.5	14.3	70.0
Southampton	12.1	10.8	7.3	1.1	-	-	-	-	-	1.1	3.5	7.3	43.2
Falmouth	4.0	5.7	2.4	1.0	-	-	-	-	-	-	0.2	1.3	14.6

The mean annual number of days of air frost varies from less than 5 in the Isles of Scilly to over 70 in central southern areas; variations from year to year (eg 1957 and 1963) can be dramatic: eg Falmouth, 1957 : 7 ; 1963 : 33 (the Isles of Scilly recorded nil and 9 in respective years).

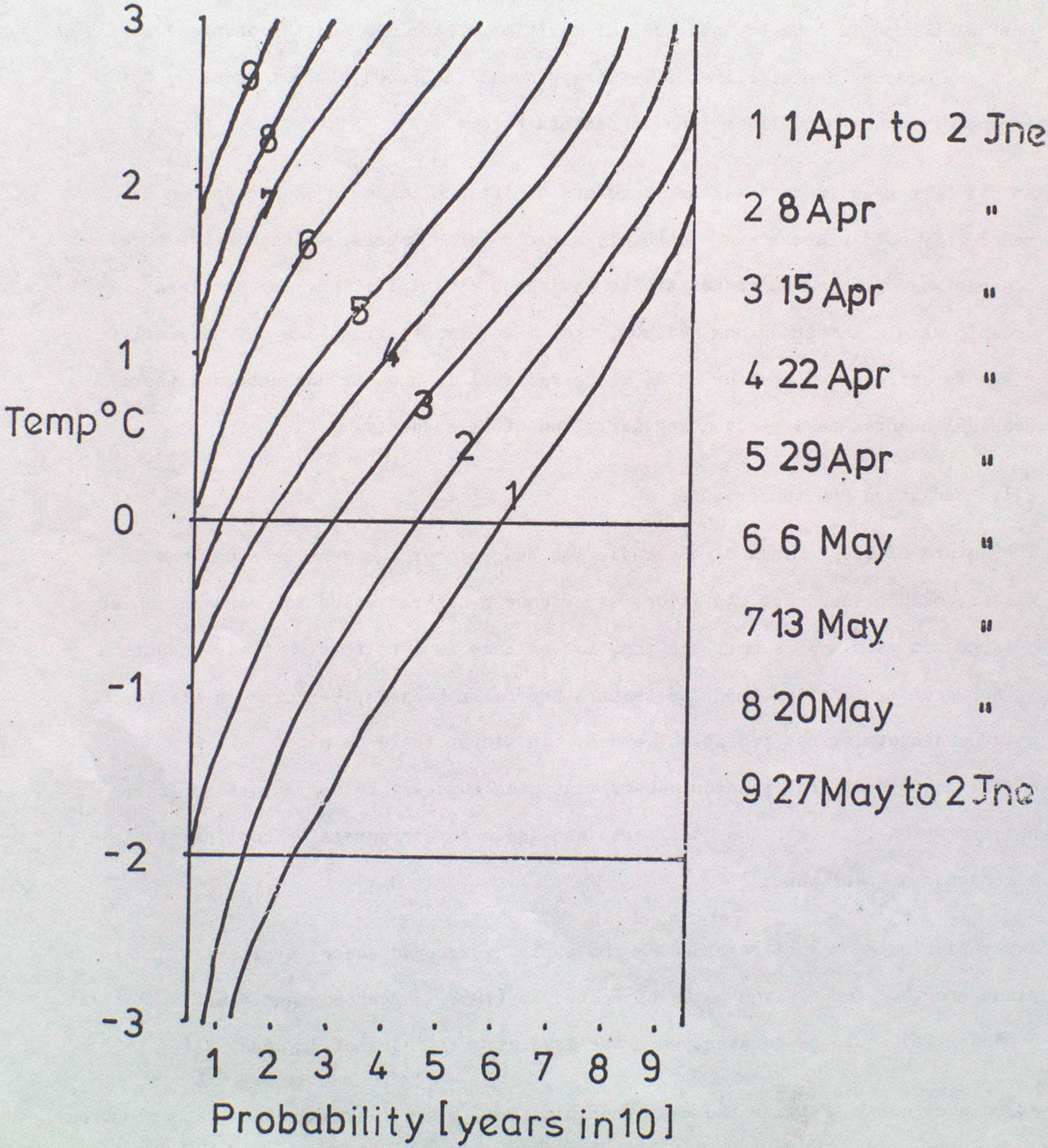
The agricultural meteorologist is often requested to comment upon likely spring frost risk in new or established enterprises. The vital dependence of frost occurrence on local topography inevitably makes such comments qualitative. It is possible however to conduct an 'in situ' survey; suitably mounted minimum thermometers are arrayed around the site and daily readings taken for a season or more over the spring period. By establishing a standard Stevenson screen on the site and relating all readings to a nearby long term climatological station it is possible to infer the probability ('years in 10') of frosts of stated severities occurring at the different locations after various dates in spring. An example of such frost frequency curves is found in fig 13.

Hogg (1968) made a rough assessment of the economic importance of frost for blackcurrants at a Somerset site, by making assumptions about the fractional crop loss as a function of temperature. He found that in 5 years out of 10 a 'wipe-out' was likely, with partial (50%) loss in two years and a full crop in the other three. If G is the "gross annual return" for a full crop, then over 10 years 10G is expected; frost damage reduces this to: 5 years x 0% x G + 2 x 50% x G + 3 x 100% x G ie to 4G.

Apart from taking sensible precautions in the siting of frost sensitive crops, frost prevention by 'sprinkling' is often carried out in this country, a technique most relevant to early potatoes and blackcurrants and able to ward off slight frost effects. It is probably unable to prevent damage under severe conditions and, in fact, in this situation the wetted crop may suffer greater damage than if left untouched.

Fig 13

Manston 1961-77
Probability of Air Frost during Spring



II THE CLIMATE OF THE EUROPEAN MAINLAND

1. Introduction

Most of Europe is open to invasions of maritime westerlies and the change from maritime to continental climates is very gradual (Lockwood, 1979); indeed marine effects are still obvious in Eastern Europe.

As has been seen in part I, the temperate maritime climate is characterised by moderately cold winters and moderately warm to warm summers. Although the more oceanic regions have an autumn/winter maximum of precipitation, and the less oceanic have a summer/autumn maximum, they have climates that are not generally given to extremes of heat or cold, where rainfall is usually adequate and where seasonal changes take place irregularly and often suddenly.

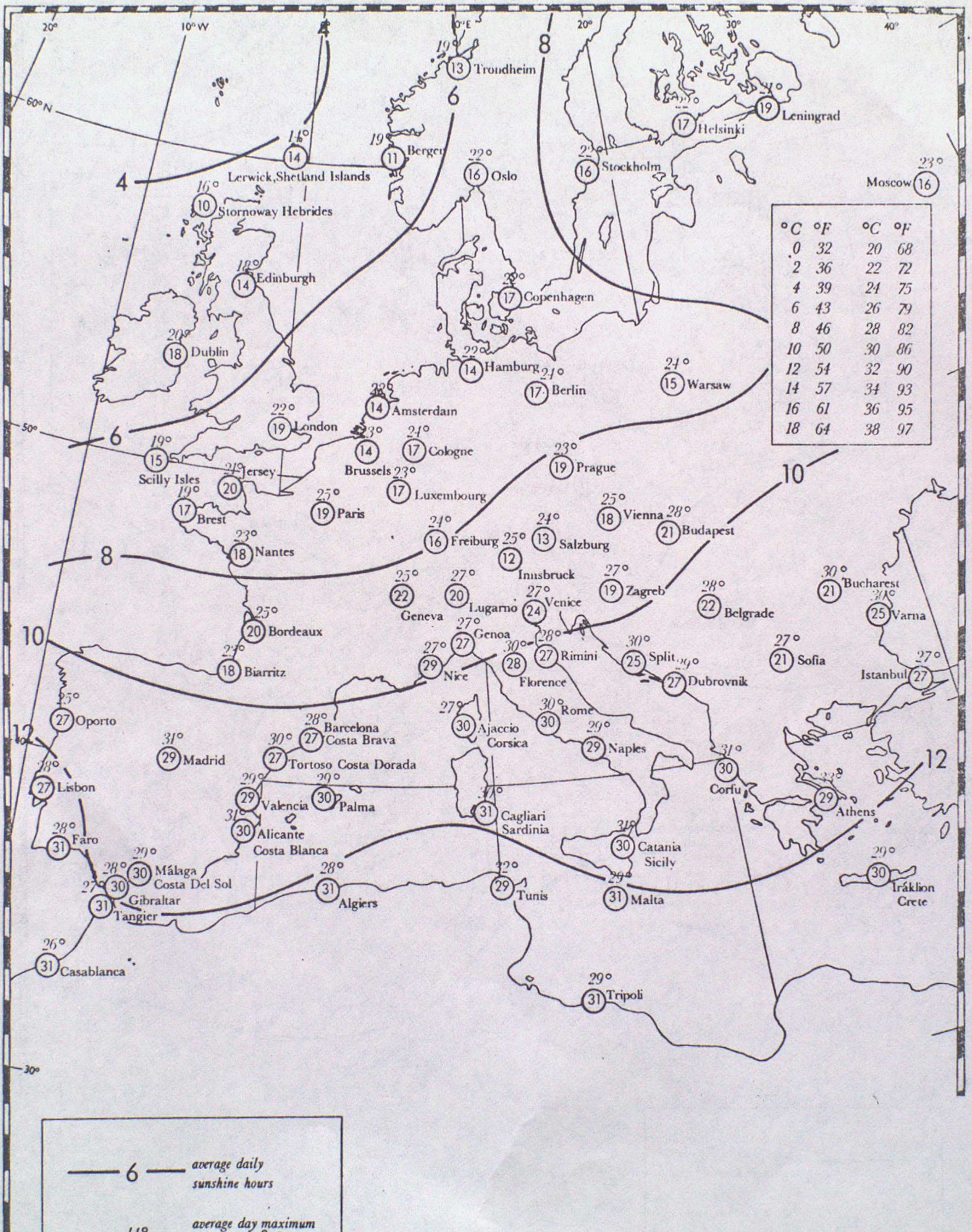
2.1. Radiation and temperature

The nature of the balance of the radiation budget over the year is such that in winter, middle (and high) latitudes experience a net radiation loss and in summer a large net gain. In summer the positive balance implies that warm air advection is not greatly important and the temperature falls towards the north in accord with the decreasing net radiation values. In winter there is a net advection of heat from the south-west that goes some way to compensate for the net radiation loss over the Continent, and leads to a progressive cooling of the air masses as they pass.

Net radiation R_N may be regarded as the basic background energy available for plant growth. For a given value of R_N Budyko (1956) suggested that plant productivity would be greatest when the 'radiational index of dryness, $\frac{R_N}{PL}$', approaches unity (P being the mean precipitation, L the latent heat of vapourisation). This index varies from below 0.3 in northern Europe to over 2 in the south, approaching unity over large areas of central western Europe. On this basis central and northern France, southern Britain and southern Sweden are regions

Fig 14a.

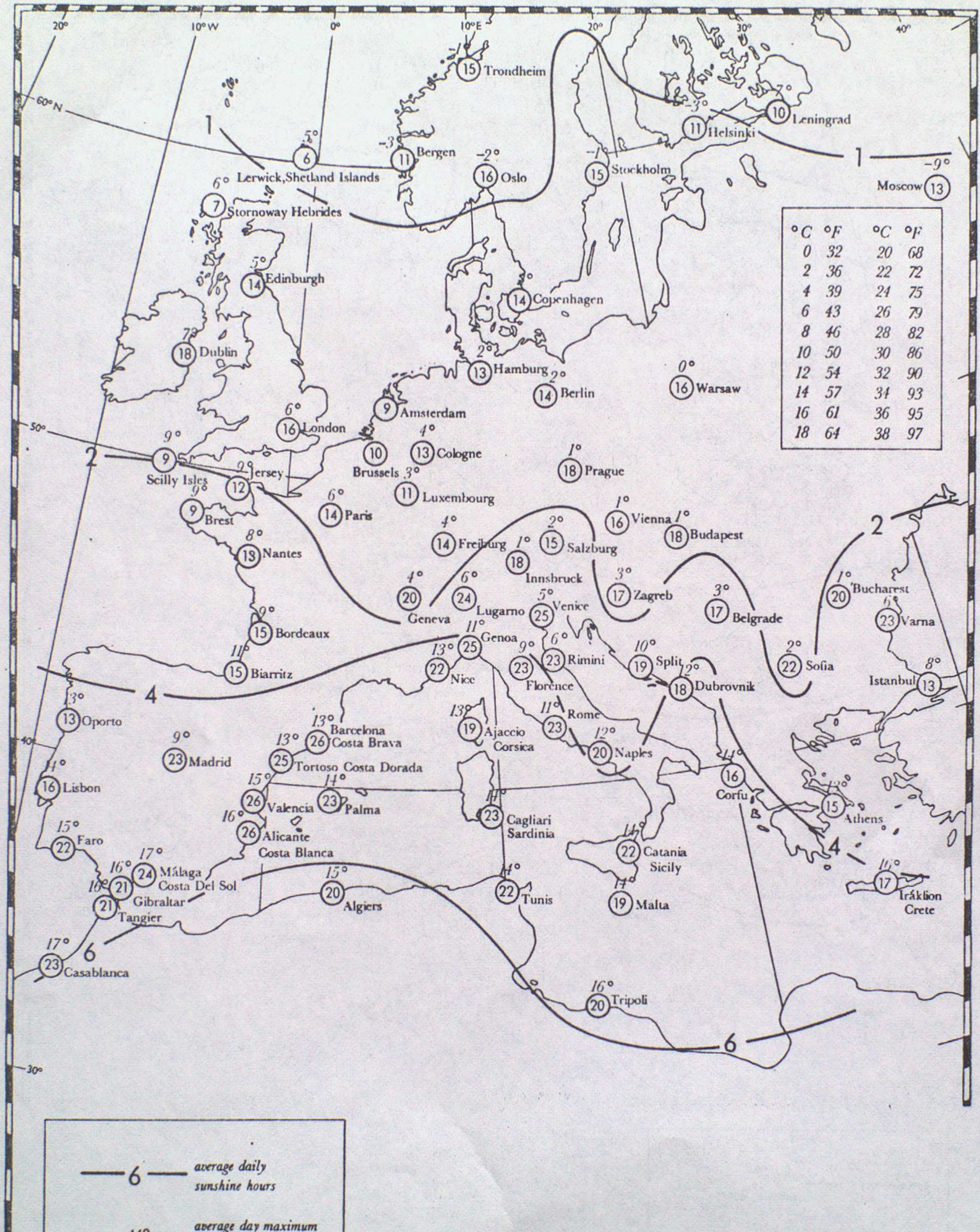
July


20°
10°W
0°E
20°
30°
40°
60°N
50°
30°
4
6
8
10
12
19° 13 Trondheim
14° 14 Lerwick, Shetland Islands
19° 11 Bergen
22° 16 Oslo
22° 16 Stockholm
22° 17 Helsinki
21° 19 Leningrad
23° Moscow 16
16° 10 Stornoway Hebrides
18° 14 Edinburgh
22° 17 Copenhagen
20° 18 Dublin
22° 14 Hamburg
24° 17 Berlin
24° 15 Warsaw
22° 14 Amsterdam
22° 19 London
23° 14 Brussels
24° 17 Cologne
19° 15 Scilly Isles
21° 20 Jersey
23° 17 Luxembourg
23° 19 Prague
19° 17 Brest
25° 19 Paris
25° 18 Vienna
28° 21 Budapest
23° 18 Nantes
24° 16 Freiburg
25° 12 Innsbruck
24° 13 Salzburg
25° 22 Geneva
27° 20 Lugarno
27° 24 Venice
27° 19 Zagreb
28° 22 Belgrade
30° 21 Bucharest
30° 25 Varna
25° 20 Bordeaux
27° 27 Genoa
28° 27 Rimini
30° 25 Split
29° 27 Dubrovnik
27° 21 Sofia
27° Istanbul 27
23° 18 Biarritz
27° 29 Nice
30° 28 Florence
25° 27 Oporto
27° 30 Ajaccio Corsica
30° 30 Rome
28° 27 Barcelona Costa Brava
31° 29 Madrid
30° 27 Tortoso Costa Dorada
29° 29 Naples
31° 30 Corfu
28° 27 Lisbon
29° 29 Valencia
29° 30 Palma
31° 31 Cagliari Sardinia
33° 29 Athens
31° 30 Alicante Costa Blanca
28° 31 Faro
31° 30 Catania Sicily
29° 30 Málaga Costa Del Sol
28° 30 Gibraltar
27° 31 Tangier
28° 31 Algiers
32° 29 Tunis
29° 31 Malta
29° 30 Iráklion Crete
26° 31 Casablanca
29° 31 Tripoli
6 average daily sunshine hours
14° average day maximum temperatures °C
15 average number of dry days

°C	°F	°C	°F
0	32	20	68
2	36	22	72
4	39	24	75
6	43	26	79
8	46	28	82
10	50	30	86
12	54	32	90
14	57	34	93
16	61	36	95
18	64	38	97

14.b.

January


20°
10°W
0°
10°E
20°
30°
40°
60°N
50°
40°
30°
1
2
4
6
(15) Trondheim
5° (6) Lerwick, Shetland Islands
-3° (11) Bergen
-2° (16) Oslo
-1° (15) Stockholm
-3° (11) Helsinki
-7° (10) Leningrad
-9° Moscow (13)
6° (7) Stornoway Hebrides
5° (14) Edinburgh
(14) Copenhagen
7° (18) Dublin
2° (13) Hamburg
2° (14) Berlin
0° (16) Warsaw
(9) Amsterdam
6° (16) London
9° (9) Scilly Isles
9° (12) Jersey
(10) Brussels
4° (13) Cologne
3° (11) Luxembourg
1° (18) Prague
9° (9) Brest
6° (14) Paris
8° (13) Nantes
4° (14) Freiburg
1° (18) Innsbruck
2° (15) Salzburg
1° (16) Vienna
1° (18) Budapest
4° (20) Geneva
6° (24) Lugarno
5° (25) Venice
3° (17) Zagreb
3° (17) Belgrade
1° (20) Bucharest
6° (23) Varna
9° (15) Bordeaux
11° (25) Genoa
13° (22) Nice
9° (23) Florence
6° (23) Rimini
10° (19) Split
12° (18) Dubrovnik
2° (22) Sofia
8° Istanbul (13)
11° (15) Biarritz
13° (13) Oporto
9° (23) Madrid
13° (26) Barcelona Costa Brava
13° (25) Tortoso Costa Dorada
13° (19) Ajaccio Corsica
11° (23) Rome
12° (20) Naples
14° (16) Corfu
13° (15) Athens
14° (16) Lisbon
15° (26) Valencia
14° (23) Palma
14° (23) Cagliari Sardinia
16° (26) Alicante Costa Blanca
15° (22) Faro
17° (24) Málaga Costa Del Sol
16° (21) Gibraltar
(21) Tangier
15° (20) Algiers
14° (22) Tunis
14° (22) Catania Sicily
14° (19) Malta
16° (17) Iráklion Crete
17° (23) Casablanca
16° (20) Tripoli
—6— average daily sunshine hours
14° average day maximum temperatures °C
(15) average number of dry days

°C	°F	°C	°F
0	32	20	68
2	36	22	72
4	39	24	75
6	43	26	79
8	46	28	82
10	50	30	86
12	54	32	90
14	57	34	93
16	61	36	95
18	64	38	97

highly favoured for horticulture. Due to higher temperatures and radiation values, areas in the south of these regions probably have a slight advantage over those to the north.

Mean January and July temperature distributions suggest that in winter most of west and north-west Europe have no months with a mean minimum temperature below 0°C. In summer monthly mean temperatures are wholly above 10°C, reaching +30°C in parts of Southern Europe; horticulturally these high summer temperatures, provided water supplies are adequate, compensate for the low winter values.

Very low temperatures are often connected with air of 'continental polar' origin from N. Russia which is warmed by continental traverse and in Britain by passage over the North Sea. Even so it can still arrive here with a sub-zero mid-day temperature. Such an air stream is rare in the extreme South-west.

Along the Mediterranean coast, cold often dry northerly winds are frequent in winter. The Mistral blows offshore, being most intense on the coast of Languedoc and Provence and especially in and off the Rhone delta where speeds of some 20 m/secs are recorded. It blows directly from high-pressure areas over Europe to low-pressure areas over the sea through the valleys of Southern Europe. (Winds of this type blow on an average of 100 days a year at Marseilles).

2.1.1. Frost risk

Few sites in Europe are completely frost-free but sloping sites adjacent to warm seas have the most infrequent incidence. Such conditions are found along the Atlantic coast of Europe allowing early crop production, especially in light soils on slopes with a southerly aspect.

However advected cold air can reduce temperature to below 0°C even on the Mediterranean coasts. Marseilles for example has records of temperatures below 0°C in every month from October to April, the lowest being caused by the winter nocturnal radiative cooling of an already dry clear polar air mass. (Manley, 1970 considers temperatures of -25°C are not impossible in severe local frost hollows in Southern England; such extreme temperatures have been reported from most of northern Europe and there is no part where the extreme minimum is likely to be above 0°C.)

High summer temperature can occur in Britain in warm, moist air of tropical origin (mainly from N. Africa); generally such air does not travel further north than Southern Europe. Föhn winds can give rise to unusually warm, dry conditions in areas as far apart as the Alps and the Moray Firth.

2.1.2 Growing season

In England this varies from about 200 days, over upland Wales to 365 days along the West coast of Wales, and lowland areas of Devon and Cornwall.

The vegetative growth period in South Denmark begins on average about 10 April and lasts for between 195 and 212 days; the available degree-days (above 6°C) are comparable to Southern Britain (Fig 15). Calculations for Southern Europe are not particularly meaningful because of the long summer dry period.

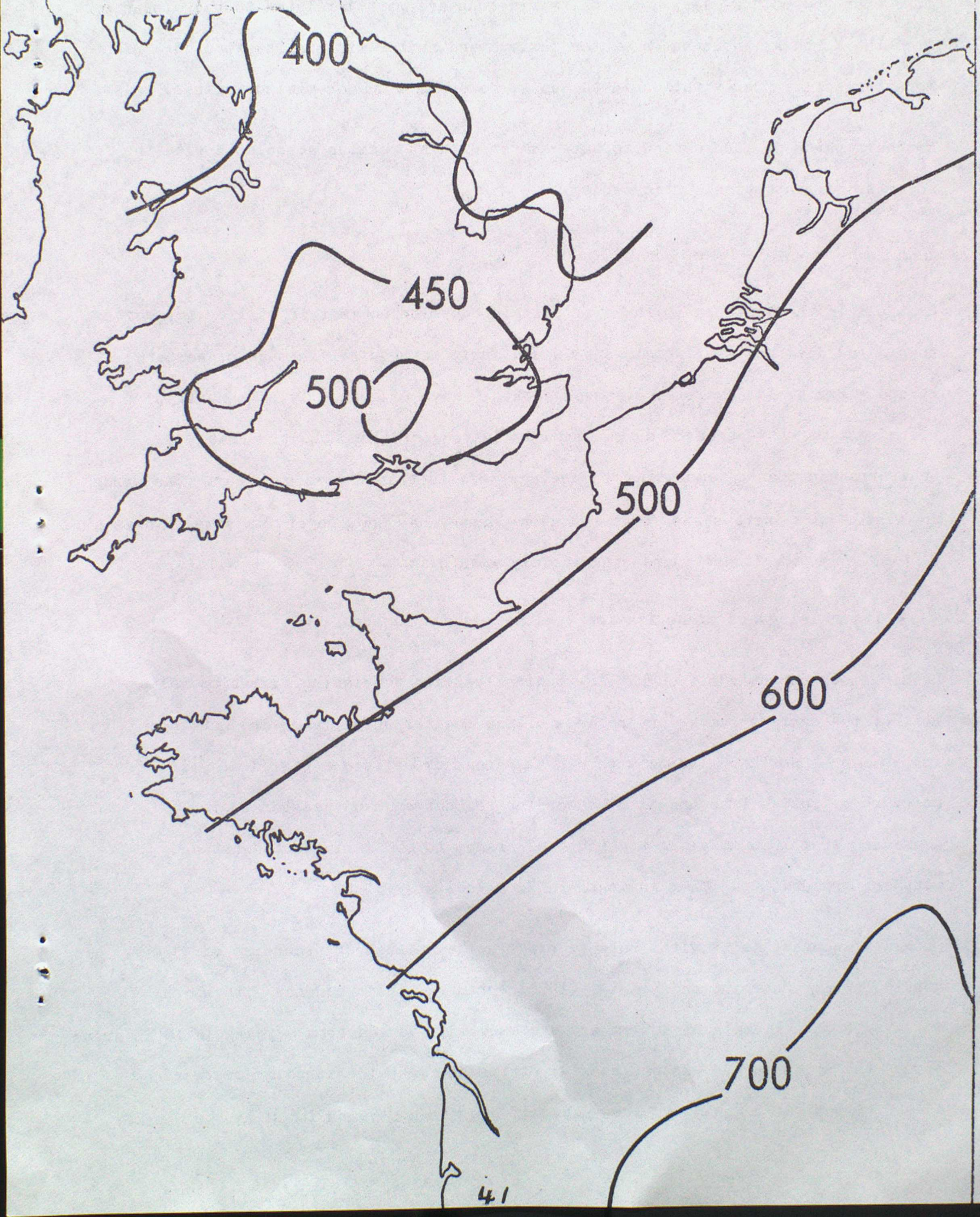
2.2. Precipitation

The average distribution of precipitation over Western Europe reflects that over the north Atlantic from whence comes much of its weather, (ie amounts increase from the Azores to Iceland with maximum precipitation in winter (Tucker, 1961)).

Cyclonic activity is less important in France, the Netherlands and Germany, than in Ireland, northern Britain and northern Europe where topography in western areas intensifies rainfall to nearly three times Tucker's north Atlantic estimates.

Fig 15

Accumulated temperature May & June
Long term average degree-days above 6°C
reduced to mean sea level


400
450
500
500
600
700

Copious precipitation is also experienced in the mountains of southern Europe but in the relatively flat areas of western and central Europe it rarely averages more than 750 mm per year. Seasonal variations are partly related to the distance from the North Atlantic but a winter maximum and summer minimum is expected; with more convective precipitation in the east, however, a summer maximum arises.

Southern parts of Europe tend to have summer drought regimes associated with the movement of subtropical anticyclones.

2.2.1. Snow

Snowfall in the southern lowlands of Britain occasions comment if it lies for more than a few days and similar comments would apply to snowfall in much of Western Europe. Paris, for example, averages about 10 days with snow lying annually, north west Germany about 20 days. Snow is infrequent along the European Mediterranean coasts, amounting on average to less than 6 days per year. Eastwards the winter cold increases so that southern Germany has snow cover for some 20 days a year on average a figure increasing rapidly with height.

2.2.2. . Potential evapo-transpiration (pe) and water balance

Pe decreases northwards (roughly latitudinally) with decreasing radiation values so that the extreme summer dry periods of the Mediterranean lands are not found in central or northern Europe although all areas experience a period of soil moisture deficit. (The annual pe according to Mohrmann and Kessler 1955, decreases from 1000 mm along the south of France to 600 mm in South-west and Southern England, to 400 mm in Northern Scotland).

Drought frequency has a vital role to play in the success or otherwise of horticulture; Mohrmann and Kessler (1955) estimated the frequency with which maximum potential smd's of 200 mm are exceeded: it varied from 9 years in 10 in areas around the southern and western coastal strips of France, (extending eastwards inland to the Paris Basin) to low values of less than 5 years in 10 in the Massif

Central and along the North coast and into South-east England. Very low values (less than 1 year in 10) were estimated for north-west Britain and the Netherlands.

In dry years, then, considerable water stress exists in Northern Europe and the lack of water can restrict plant growth over wide areas. The low altitudinal limit to cultivation in extreme western Europe has partly been explained as due to temperature but water balance will also play a role. The rapid increase of precipitation with height (coupled with only a slight decrease of pe) results in water excess in upland areas in every month of the year - even at quite low altitudes.

Duckam and Masefield (1970) present climate 'pen pictures' of the near continent; these will now be summarised aided by 'climate transects'.

3. Climate of the Netherlands : cool, humid ; the average annual precipitation is between 635 and 890 mm being remarkably reliable (co-efficient of variance < 10%) but is distributed among more "rain days" than most other European countries (eg see Fig 14). Mean daily sunshine hours are between 4.0 and 4.6 with a growing season of 9 months during which the mean pe is 600 mm.

The annual temperature range is rather greater than in Britain (see table 5 and 22); the January and July means at Vlissingen are 3.0°C and 17.3°C respectively compared with 4.5°C and 16.8°C at Dover. Frost is a problem inland.

3.1. Transects

i. West Holland : mild winter, cool summer, sunshine 4.3 hr/day annual average rainfall 689 mm evenly distributed with a slight late-summer peak. Mean daily maximum temperature reaches 20.9°C in August. The Westland area is particularly well suited to intensive horticulture, the fertile medium dry or peat soils being sheltered by coastal dunes from the prevailing westerlies.

South-east Holland is more continental with a higher mean summer maximum of

Table 23

Eelde 53°08′N 6°35′E 4 m

Period 1946–60 Bibliography 44	Temperature						Relative humidity		Precipitation			Bright sunshine			
	Average daily		Average monthly		Absolute		Average of observations at		Average monthly fall	Maximum fall in 24 h	Average No. of days with 0·1 mm or more	Average monthly duration	Average per cent of possible	Maximum duration in one day	Average No. of days with no sun
	Max.	Min.	Max.	Min.	Max.	Min.	0730	1330							
	degrees Celsius						*per cent*		*millimetres*			*hours*		*hours*	
January	3·7	−1·0	9·8	−9·0	12·2	−15·7	91	85	69	22	21	51	20	7·7	15
February	3·8	−1·6	10·9	−9·8	16·0	−22·9	90	81	50	24	19	66	24	9·7	11
March	7·8	0·5	16·4	−5·8	20·2	−14·4	89	73	44	24	17	107	29	11·6	7
April	12·5	3·3	20·5	−2·3	24·4	−3·9	81	63	45	25	16	176	42	13·6	3
May	16·7	6·8	24·4	−0·2	29·7	−3·3	77	62	53	31	15	212	43	15·4	2
June	19·6	9·8	27·9	4·1	33·3	1·5	77	64	58	32	15	204	40	15·7	2
July	21·0	11·9	28·1	6·5	33·2	3·7	81	67	86	45	18	181	36	15·4	4
August	20·9	11·7	27·2	6·2	31·5	3·6	85	67	95	56	19	166	36	13·4	2
September	18·6	9·8	25·6	3·9	31·8	0·8	88	69	75	53	18	141	37	12·1	3
October	13·7	6·0	19·1	−0·4	24·5	−3·7	91	74	57	22	20	81	25	9·8	10
November	8·4	2·8	13·0	−3·7	15·5	−7·6	93	84	71	30	22	52	20	8·3	13
December	5·4	0·6	11·0	−6·7	13·4	−14·6	93	89	64	51	22	29	12	7·4	17
Year	12·7	5·1	30·4*	−12·9*	33·3	−22·9	86	73	767	56	222	1465	30	15·7	89
No. of years	15	15	15	15	15	15	15	15	15	15	15	9	9	9	9

Winterswijk 51°58′N 6°43′E 33 m

Period 1931–60 Bibliography 44	Temperature						Relative humidity		Precipitation			Bright sunshine			
	Average daily		Average monthly		Absolute		Average of observations at		Average monthly fall	Maximum fall in 24 h	Average No. of days with 0·1 mm or more	Average monthly duration	Average per cent of possible	Maximum duration in one day	Average No. of days with no sun
	Max.	Min.	Max.	Min.	Max.	Min.	0730	1330							
	degrees Celsius						*per cent*		*millimetres*		*hours*			*hours*	
January	3·8	−1·3	10·6	−9·8	13·8	−27·4	89	80	65	33	20	—	—	—	—
February	4·8	−1·1	11·6	−9·9	17·3	−24·5	88	75	57	57	17	—	—	—	—
March	9·4	1·1	17·7	−5·6	21·6	−12·8	84	63	46	23	15	—	—	—	—
April	13·6	3·9	21·3	−2·1	27·7	−5·7	78	58	51	53	15	—	—	—	—
May	18·2	7·2	26·7	−0·1	32·6	−4·4	74	56	49	44	14	—	—	—	—
June	21·2	10·3	29·4	3·5	35·0	1·5	75	58	62	36	14	—	—	—	—
July	22·5	12·5	30·4	7·0	36·2	3·2	80	62	87	40	17	—	—	—	—
August	22·3	12·3	30·1	6·4	37·6	3·5	83	62	81	68	17	—	—	—	—
September	19·3	9·9	26·7	3·0	32·1	−2·5	86	65	69	34	16	—	—	—	—
October	13·9	6·2	20·0	−1·4	25·4	−8·5	89	71	64	36	19	—	—	—	—
November	8·5	3·1	14·4	−3·6	19·9	−7·6	91	80	62	37	19	—	—	—	—
December	5·0	0·3	11·5	−8·1	16·4	−17·8	90	84	62	47	20	—	—	—	—
Year	13·5	5·4	32·4*	−13·4*	37·6	−27·4	84	68	755	68	203	—	—	—	—
No. of years	30	30	30	30	30	30	30	30	30	30	30	—	—	—	—

Vlissingen (Flushing) 51°28′N 3°35′E 1 m

Period 1931–60 Bibliography 44	Temperature						Relative humidity		Precipitation			Bright sunshine			
	Average daily		Average monthly		Absolute		Average of observations at		Average monthly fall	Maximum fall in 24 h	Average No. of days with 0·1 mm or more	Average monthly duration	Average per cent of possible	Maximum duration in one day	Average No. of days with no sun
	Max.	Min.	Max.	Min.	Max.	Min.	0700	1300							
	degrees Celsius						*per cent*		*millimetres*			*hours*		*hours*	
January	5·0	1·0	10·2	−5·0	12·5	−14·5	89	82	62	29	20	53	20	7·9	13
February	5·1	0·6	10·6	−5·7	16·7	−19·6	87	80	45	18	17	69	25	9·8	10
March	8·5	2·5	15·3	−2·5	20·4	−5·9	87	72	40	33	16	130	35	11·2	6
April	11·9	5·4	19·4	0·9	26·3	−2·1	81	67	41	23	15	166	40	13·5	3
May	15·9	8·7	24·1	3·6	29·7	1·3	78	65	42	41	13	211	44	15·4	2
June	19·0	12·0	26·8	7·5	32·8	4·3	78	66	50	35	12	224	45	15·5	1
July	20·6	14·1	27·6	10·0	34·0	6·3	81	68	71	54	15	204	41	15·2	1
August	20·9	14·4	27·5	10·5	33·4	7·0	82	68	65	34	15	195	43	14·5	1
September	18·7	12·6	25·0	7·9	33·0	4·5	84	69	73	56	16	147	39	12·4	3
October	14·1	8·9	19·1	2·8	26·0	−2·8	87	74	70	31	19	101	31	10·8	6
November	9·4	5·2	13·9	−0·3	17·2	−4·9	89	82	72	57	20	51	19	8·9	11
December	6·3	2·4	11·4	−4·0	14·5	−13·5	89	85	58	39	20	37	15	7·2	15
Year	13·0	7·3	29·8*	−8·3*	34·0	−19·6	84	73	689	57	198	1588	33	15·5	72
No. of years	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

22.5°C in July at Winterswijk and a greater July diurnal range (10°C compared with 6.5°C at Vlissingen). Mean winter temperatures are 1 to 2°C lower than near the western coast. The average annual precipitation is 755 mm at Winterswijk compared with 689 mm at Vlissingen and has a marked peak in July and August.

The peat colonies of the north-east Netherlands are notorious for late killing spring frosts; on the clays nearer the coast the proximity of the sea delays the spring rise in temperature. Wind is also a problem in this flat open countryside. A north-south climate sector is presented in table 23.

4. Climate of France: **The climate ranges from cool-humid in the north west (average annual** precipitation 635-750 mm) to warm, semi-humid in the south west (precipitation 685 - 815 mm) and warm-dry (Mediterranean) in the south-east (precipitation 500 - 635 mm). The growing season mean temperatures vary from 13°C in the north to 14°C in the south where, however, the mean summer temperature (June to September) is some 4°C higher than in the north as may be seen in comparing the transect stations (table 24) Montpellier (20.8°C) with Boulogne (16.0°C).

Much of the land, particularly along the south-east coast, suffers from drought in summer aggravated by moisture loss encouraged by wind. A serious problem in the areas most liable to moisture deficit is the uncertainty in summer rainfall: the coefficient of variance ranges from 10 to 15% in the north to 20% in the south-east. (viz. Montpellier : July to September rainfall 20 mm to 100 mm, table 24). This is clearly one of the main hazards for fruit, vegetables and vineyards. Frost too, is an important hazard in the south-east.

4.1. North-south Transects

i. Nord

Growing season 9 months, mean temperature during this time of 12.9°C (at Lille); rainfall 750 mm with a January mean of 3°C and July 18°C. Some 60 frost days and 175 rain-days. The climate is somewhat more continental than South-east

England and summer droughts prove more of a problem than winter cold.

ii. Paris Basin

An area that has a lower precipitation than Nord as well as a shorter growing season (7 months) although the mean growing season temperature is higher (viz 14.7°C at Rheims which has a January mean of 2°C and July mean of 18.3°C). Some 74 days of frost and 164 days of rain in its eastern half; the Paris Basin is more continental than Nord.

iii. Burgundy

An area compounded of maritime continental and Mediterranean influences! Precipitation of 750 mm is not very reliable and rigorous winters and sudden cold spells are offset by warmer springs and mild autumns of Mediterranean origin.

The growing season is 8 to 9 months; at Lyon the mean January temperature is 2.2°C and July 20.7°C. These are some 62 frost days and 145 rain days. The summer heat and attendant droughtiness are problems.

iv. Mediterranean

Although the growing season is 12 months long, the low summer rainfall is highly variable (c.v. 20%). Insolation in spring (7.2 hours per day,) January mean of 5.9°C and July of 22.3°C with 37 frost days, 88 rain-days. The cold Mistral from the north has a profound effect especially west of Marseilles; shelter protection is advisable.

Table 2.4

Boulogne-sur-Mer 50°44′N 1°36′E 73 m

Period 1931–60 Bibliography 13, 14, 16	Temperature						Relative humidity		Precipitation			Bright sunshine			
	Average daily		Average monthly		Absolute		Average of observations at		Average monthly fall	Maximum fall in 24 h	Average No. of days with 0·1 mm or more	Average monthly duration	Average per cent of possible	Maximum duration in one day	Average No. of days with no sun
	Max.	Min.	Max.	Min.	Max.	Min.	0600	1200							
			degrees Celsius				*per cent*		*millimetres*			*hours*		*hours*	
January	6·0	1·9	11·5	−4·7	12·8	−10·8	88	85	57	26	18	—	—	—	—
February	6·2	2·0	12·3	−5·1	17·2	−13·6	87	83	45	18	14	—	—	—	—
March	9·2	3·3	16·9	−2·1	19·0	−6·2	87	77	37	14	13	—	—	—	—
April	11·8	6·1	20·5	1·6	26·0	−1·0	85	73	33	43	14	—	—	—	—
May	15·2	8·7	23·0	4·1	29·6	1·8	85	75	39	27	13	—	—	—	—
June	17·7	11·6	25·7	8·0	31·4	6·0	87	77	36	40	11	—	—	—	—
July	19·7	13·9	27·3	10·1	33·6	8·4	88	78	41	28	12	—	—	—	—
August	20·0	14·3	26·3	10·8	32·0	9·0	89	78	47	32	13	—	—	—	—
September	18·4	12·8	24·6	8·3	30·8	5·8	88	77	56	36	14	—	—	—	—
October	14·3	9·7	19·9	3·1	24·8	−3·0	87	78	65	25	14	—	—	—	—
November	10·0	5·7	14·6	−0·7	18·4	−5·2	87	83	87	44	16	—	—	—	—
December	7·2	3·2	12·5	−2·3	16·8	−7·6	88	86	56	19	18	—	—	—	—
Year	13·0	7·8	29·5*	−7·1*	33·6	−13·6	87	79	599	44	170	—	—	—	—
No. of years	30	30	13	13	13	13	13	13	30	13	30	—	—	—	—

Nevers 47°00′N 3°06′E 176 m

Period 1931–60 Bibliography 13, 14, 15, 16	Temperature						Relative humidity		Precipitation			Bright sunshine			
	Average daily		Average monthly		Absolute		Average of observations at		Average monthly fall	Maximum fall in 24 h	Average No. of days with 0·1 mm or more	Average monthly duration	Average per cent of possible	Maximum duration in one day	Average No. of days with no sun
	Max.	Min.	Max.	Min.	Max.	Min.	0600	1200							
			degrees Celsius				*per cent*		*millimetres*			*hours*		*hours*	
January	6·3	−·07	13·3	−9·0	15·2	−18·0	89	79	67	25	17	83	30	—	—
February	7·6	−0·4	15·5	−9·1	23·5	−21·8	89	73	55	28	15	113	39	—	—
March	12·8	1·8	20·7	−6·1	26·7	−14·0	88	62	48	34	12	177	48	—	—
April	15·6	3·8	24·2	−2·6	30·0	−5·6	87	57	51	117	13	208	51	—	—
May	19·3	7·6	27·0	−0·1	30·4	−4·8	87	59	76	46	14	253	54	—	—
June	22·5	10·8	30·8	5·4	35·2	3·3	88	61	75	37	12	244	51	—	—
July	24·6	12·2	33·0	6·7	38·7	3·4	87	58	60	58	12	255	53	—	—
August	24·2	12·0	32·2	6·0	40·0	2·9	90	58	68	38	13	252	57	—	—
September	21·5	9·8	29·3	2·6	33·9	−4·0	92	63	67	63	13	215	57	—	—
October	16·0	5·8	23·8	−2·7	26·1	−8·9	93	71	69	54	14	158	47	—	—
November	10·1	3·0	17·6	−5·1	22·7	−9·8	90	77	66	81	15	82	29	—	—
December	6·5	0·6	14·2	−7·7	19·2	−16·8	90	81	70	38	16	62	23	—	—
Year	15·6	5·5	33·8*	−12·8*	40·0	−21·8	89	67	772	117	166	2102	47	—	—
No. of years	30	30	21	21	21	21	17	17	30	15	30	10	10	—	—

Montpellier/Fréjorgues 43°35′N 3°58′E 5 m

Period 1931–60 Bibliography 13, 14, 16	Temperature						Relative humidity		Precipitation			Bright sunshine			
	Average daily		Average monthly		Absolute		Average of observations at		Average monthly fall	Maximum fall in 24 h	Average No. of days with 0·1 mm or more	Average monthly duration	Average per cent of possible	Maximum duration in one day	Average No. of days with no sun
	Max.	Min.	Max.	Min.	Max.	Min.	0630	1230							
			degrees Celsius				*per cent*		*millimetres*			*hours*		*hours*	
January	10·5	1·2	17·9	−5·9	20·6	−15·0	82*	63	56	74	8	145	50	—	4
February	12·0	1·7	18·5	−5·9	21·2	−16·7	79	55	30	37	6	166	56	—	3
March	14·9	5·0	20·8	−2·4	26·2	−6·4	83	59	72	54	8	206	56	—	4
April	17·6	7·5	24·2	1·6	29·8	−0·9	80	57	56	36	8	251	62	—	2
May	21·0	10·8	26·9	5·4	32·6	1·4	79	58	47	53	9	275	60	—	2
June	25·5	14·0	31·2	8·8	34·5	5·4	75	52	33	85	5	323	70	—	1
July	28·5	16·2	33·7	11·9	36·7	9·2	70	46	20	30	3	369	79	—	0
August	27·7	16·2	33·1	11·1	36·3	8·2	79	51	40	101	6	304	70	—	<1
September	24·6	14·0	30·1	7·8	34·0	5·0	85	55	100	110	7	249	66	—	1
October	19·8	9·6	25·0	1·9	27·3	−0·6	86	59	95	117	9	185	54	—	3
November	14·9	5·4	20·8	−2·0	24·3	−5·0	83	61	70	77	9	145	50	—	5
December	11·1	2·3	17·4	−3·3	19·3	−7·1	84	66	90	104	10	124	45	—	6
Year	19·0	8·7	34·5*	−7·9*	36·7	−16·7	80	57	709	117	88	2742	61	—	31
No. of years	30	30	14	14	14	14	14	14	30	15	30	15	15	—	10

III CLIMATIC TRENDS: THEIR IMPLICATIONS FOR AGRICULTURE AND HORTICULTURE

1. Introduction

By using selected varieties, methods of cultivation etc, horticultural and agricultural systems continue to evolve to make the optimum use of our present climate (Carter, 1978). However, quite small changes could have a profound effect on potential crop yields through their influence on the time available for soil working and pest and disease incidence as well as the direct weather influence on plant development. Adverse social and economic effects of relatively local climate extremes have been well demonstrated, for example the effect on potato production of the abnormally wet spring of 1975 followed by the dry summer and the dry arid summer of 1976.

In a recent MAFF study Wilkinson (1978), in collaboration with the Meteorological Office, surveyed the possible agricultural significance of and remedies for, climatic change. He summarised the present position of climate change research as follows:

i. It is apparent from the literature that there is no firm scientific basis for predicting climatic behaviour on time scales of centuries, decades or even years.

ii. The 'natural state' of the climate is one of variability but our understanding of the mechanisms at work and the causes of climatic trends is inadequate.

iii. From all scientific evidence it is apparent that no confident statement can be made concerning the long-term trends except to state that the probability of any change appears to be towards a cooler epoch, while in the short-term (scale of tens of years) Man's influence is likely to dominate, causing warming through the continual addition of products of combustion into the atmosphere, and encouraging the so-called 'glass-house'effect' by the absorption of long-wave radiation.

2. Implications of a change in mean UK air temperature

In looking at the implications of a long term temperature deviation of ±1°C from the present mean UK air temperature Wilkinson pointed out that such a change could mask considerable variability within the year citing the hot arid summer and the cool wet autumn/winter of 1976.

The influence of a ±1°C deviation in air temperature on certain agro-meteorological parameters can be estimated with the broad intention of indicating possible physical implications and their corresponding agronomic and economic significance.

2.1. Growing Season

The effect of changes of ±1°C in mean air temperature on the mean monthly soil temperature at 30 cm would depend on location, and might be associated with changes in the length of the growing season ranging from ± 30 days in south-west England and south Wales decreasing to ± 20 days in the north of the country and upland areas.

2.2. Land Capability

The potential for cropping could be reduced by a 1°C decrease; a temperature increase could increase plant moisture stress on soils of low available water capacity (awc); soil with a high awc would attain an enhanced value. A reduction in growing days would emphasize the importance of correct land management decisions; an increase would allow greater flexibility over the whole range of horticultural and agricultural activities.

2.3. Crops

Fewer growing days would adversely affect the development and yield of temperature-sensitive or late maturing crops like French beans and potatoes. A temperature increase would produce opposite positive effects but the corresponding effect on pest and disease hazards must be reckoned with. Thus the totality of risk may be little affected but the type could significantly alter.

Extreme heat or cold might interfere with biological cycles either decreasing risks or inducing environments favourable to the explosive spread of pest or disease.

2.4 Soil moisture deficits (smd's) and irrigation need.

The potential evapo-transpiration (pe) over the summer months would change by some ± 25 mm; in terms of increased irrigation need + 25 mm represents some 3% of the total average annual rainfall, the greatest impact being in low-rainfall areas and in years of significantly below-average rainfall. Some improved response from irrigated crops would be expected particularly among those crops where benefits are at present only marginal. A decrease in pe might increase the flood hazard of certain low-lying areas.

The influence of ± 25 mm pe change on the estimated return to field capacity date is tabulated below (Wilkinson, 1978, table 3) in table 25.

Table 25

Area	Rainfall	Av date of return	Days change from the average date of return to field capacity for a change of ± 25 mm in pe	
			+25 mm	-25 mm
Midlands	840	14/10	+14	-22
	585	23/11	+ 7	- 8
South-east	635	26/11	+14	-11
	508	12/12	+5	- 5
South-west	1200	4/10	+10	- 6
	760	13/11	+ 3	- 9
Wales	760	28/10	+ 8	-15

2.5 Temperature

A long-term mean temperature of 1°C above the present normal and the periods of high temperature implied could adversely affect plants at sensitive critical growth stages (particularly likely in central, eastern and southern England). Sustained high temperature would generate changes towards the more compatible species/varieties such as are grown in Central Europe; aphid activity areas would be likely to extend northward.

Below average temperatures would increase snow-cover in the lowlands and the late and early frost hazard (although local topography plays a major rôle here as has been seen in part I) such that acceptable risk limits for sensitive crops are bound to be exceeded. Fresh vegetable supplies in winter and spring would be particularly susceptible but the groundkeeper problem following potatoes, for example, could be eliminated and soil tilths resulting from winter weathering substantially improved. A significant alteration in the spectra and dynamics of plant pest and disease problems might occur due to the elimination of over-wintered inoculant and the reduction in aphid survivial and enhanced predator survival. The impact of such temperature change, however, will be a function of altitude, coastal proximity, local shelter etc.

2.6. Fuel requirement for glasshouses

Calculations for Cranwell, Lincs, suggest that a reduction in mean temperature of 1°C would bring an 18% increase in fuel use in maintaining a 15.5°C internal temperature for 39 weeks from 1 February to 31 October; for a mean increase of 1°C a 16% fuel saving would result. Extrapolation suggests this constitutes a percentage increase (or decrease) in the average fuel costs for the total hectarage of horticultural glass in England and Wales of 20 to 25%. The consequence would be a re-appraisal of the hectarage under glass.

Historically all the extreme situations referred to have been experienced in Europe over short periods in the recent past.

3. CO_2 concentration changes

Photosynthesis and respiration in a plant respond not only to the temperature and the flux density of radiation in the photosynthesis waveband, but also to CO_2 concentration in the ambient air. As early as 1863 Tyndall expressed the opinion that changes in CO_2 concentration could influence the climate near the earth's surface by selective absorption of long wave radiation; Manabe (1971) calculated that doubling the present (330 ppm) concentration would increase the average surface temperature by 2°C. (It is probable, according to a 1971 MIT report on Inadvertant Climate Modification; that relative humidity would not be greatly affected).

The actual increase in airborne concentration of CO_2 due to the continued burning of fossil fuels will depend on the fraction of the generated CO_2 that remains airborne. Current estimates indicate a concentration increase to 375 ppm by 2000 AD which will lead to increased CO_2 assimilation by the leaf; the problem remains of how this assimilate is divided between that which is respired and that which is built into new tissue (de Witt et al 1970).

The net effect, though, is likely to be an amelioration in crop growth and productivity; the implications of this section, too, are that in the short term, anyway, Man's influence on the climate is likely to lead to warming.

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Any comments or suggestions on this paper should be sent to the author.

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